SUBJECTIVE REACTION TO WHOLE-BODY VIBRATION

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SUBJECTIVE REACTION TO WHOLE-BODY VIBRATION

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"Research On
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On Human Performance"

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ABSTRACT

Ten male volunteers were utilized in a study of the perception of vibration. Four subjective reaction levels: perceptible, mildly annoying, extremely annoying, and alarming were established. The Boeing Human Vibration facility, modified since previous tests, was used as the test instrument. Experimental controls and test methods were determined in a preliminary study.

Subjective levels identified are generally at higher acceleration values than those of previous research. Possible reasons for the differences are discussed. Also, individual values established at a given subjective level are shown to be influenced by the magnitude of the immediately preceeding vibration level. Physiological effects in the main correlate with previous findings.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

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INTRODUCTION

Vibration and its effect on the human have been of interest to vehicle and system designers for many years. The advent of high performance, low altitude, and manned space systems however, have established increased interest in the low frequency, high amplitude regions of the vibration spectrum rather than the high frequency, low amplitude range associated with propeller systems. Research efforts in turn have reflected this trend.

A number of studies, 3, 4, 5, 6, 7, & 8, have been performed to determine human response and tolerance to low frequency sinusoidal vibration, however, results vary considerably with little or no basis provided to resolve the differences. Subjects have been tested standing, seated in different configurations and lying down. Various restraining systems have been used under a variety of experimental and environmental conditions. Criteria employed have been referenced to passenger comfort, land vehicle operation, and left completely unstructured with subjects providing their individual interpretations. And finally, subjects have had no control over the vibration received except to stop the vibration producing mechanism.

The purpose of this study was to establish a series of subjective curves utilizing the descriptive levels of Parks & Snyder [7], which would reflect subjective response to sinusoidal vibration in the seated position. An attempt was made to determine, through preliminary tests, factors which could influence responses and to control or specify these factors to a point where resulting curve positions would reflect only variations in the vibration received.

PRELIMINARY TESTS

A number of preliminary tests were conducted in the vibration facility prior to the final establishment of a test configuration. These tests, using the investigators, facility engineers and previous vibration test participants as subjects were for the express purpose of determining factors which could influence test results and to determine which of several alternate methods of control would be most effective in eliminating or reducing these influences. Summaries of test results and selected solutions follow.

Visual Effects

Subjects ability to reference the vibrating platform to the non-vibrating environment was found immediately to affect not only determination of threshold levels (as was suspected) but the "feeling" of the intensity of vibration at higher levels and the repeatability of amplitudes for given levels on successive runs. Elimination of this cue was handled through painting the test room sage green, color 34092, to minimize specular reflections and by eliminating all light sources in the area except those from the display which vibrated with the subject. All commands to the subject and feedback indications of his control action were incorporated into the display to assure his attention to the vibrating platform. Also, because of a requirement for visual monitoring by the attending physician, a "halo light" border was incorporated which would provide an adequate amount of subject illumination. Thus, the subjects even if disposed to do so, could see nothing in the test area off the vibrating platform.

Auditory Effects

Noises generated by the hydraulic pumps, lines, valves, etc. and table bearings were found to provide minimal cues at and around the perceptible level. Although not normally noticeable, with the proper set, slight changes in pitch and flow noise could be detected as the vibration equipment changed from a steady to a vibrating state. No cues were discernible as the vibration intensity increased.

Elimination of auditory cues was accomplished in two steps: Initially all sound sources and the test room were insulated with sound absorbing material, and secondly, remaining noises generated in the range where cues were provided, were analyzed and masked by addition of a white noise.

Kinesthetic Effects

Related somewhat to auditory effects are the problems associated with the wearing of headphones or a helmet. In all tests made, anything worn on the head became annoying in itself or distracting to the subject during higher vibration levels. As a consequence, a "hot" microphone on the panel and a horn speaker beneath the display were used for subject-experimenter communications during the reported program.

Also, a source of great variability in the sensation of vibration was found associated with the seating position of the subject and the associated seat and foot rest configurations. Seat back type and angle and the manner in which the subject utilized it as support produced excessive variation even within the same individual. Foot rest type and angle produced similar differences to a lesser degree. To minimize differences a single adjustable back rest located at about the first lumbar vertebra and an adjustable felt covered foot rest were utilized. Adjustments were thus possible for each subject to maintain an angle of approximately 90° between body and upper leg, 110° between upper and lower leg and 90° between lower leg and foot.

A single lap belt was found most satisfactory as a restraining device, however, differences were noted as belt tension varied. An adjustment mechanism was thus incorporated whereby tension could be set at a pre-determined level. Thirty pounds was selected for use in the final tests.

Perhaps the most significant of the preliminary test findings was that concerning the control of the vibration input. It was discovered that if the subject were allowed to directly control the severity of the vibration encountered, apprehension concerning the test and equipment was nearly eliminated and levels could be established "much more accurately" than by any of several other methods tried and used in previous programs. Means were therefore provided whereby the subjects could control amplitude within predetermined limits at any selected frequency.

METHODOLOGY

Experimental Subjects

Subjects used in the experiment were ten male employees of the Airplane Division of the Boeing Company. Nine of the ten were new to vibration research; the tenth had participated in several previous studies. All subjects were selected through a screening process which included a comprehensive physical examination to assure excellent health of the experimental group. Age, height and weight of the subjects are listed in Table I.

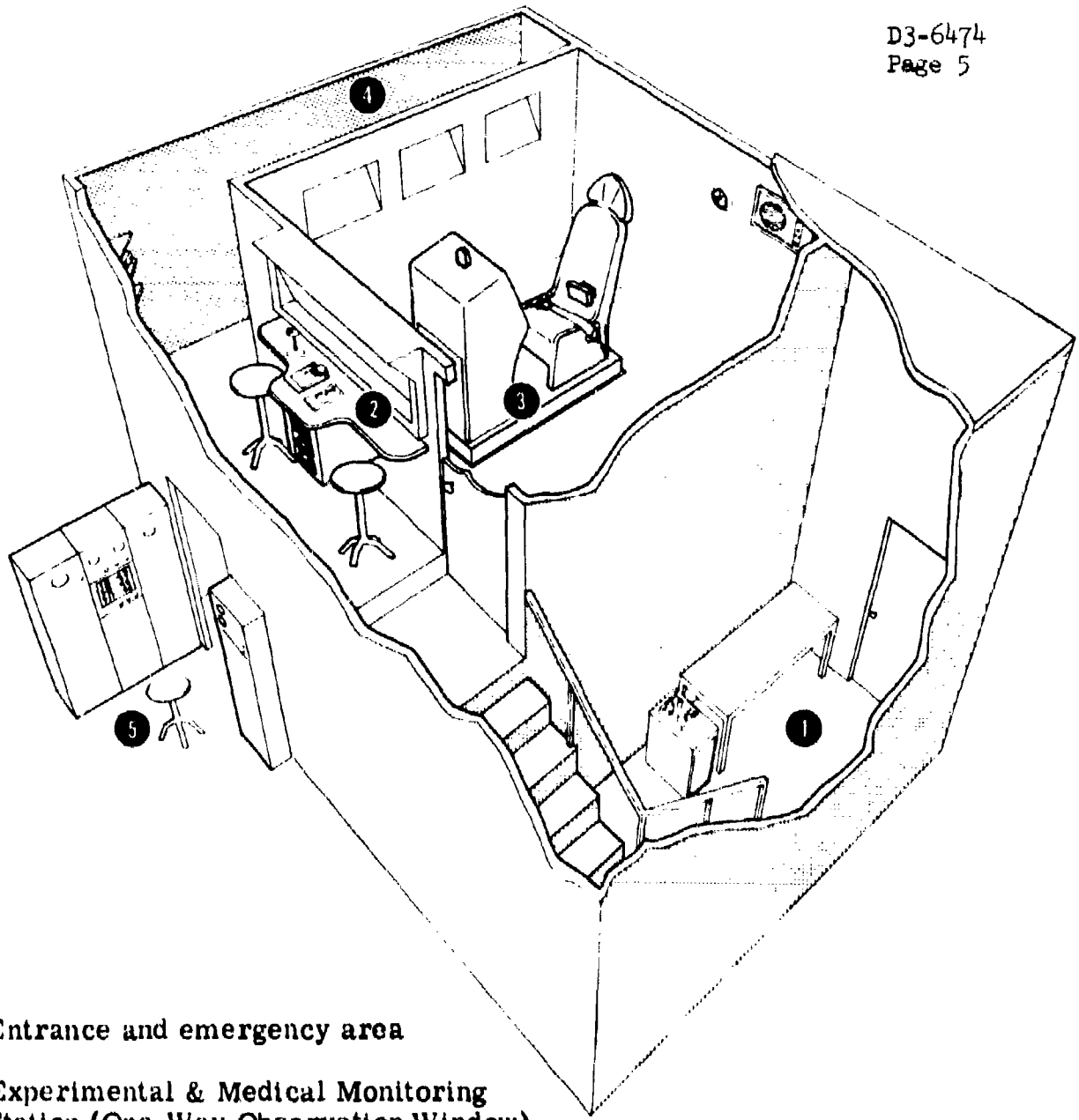
TABLE I

Experimental Subject Data

Subject	Age	Height	Weight
1	28	75	200
2	25	74	215
3	31	71	170
4	30	70.5	174
5	31	69.5	150
6	44	68	158
7	31	66	155
8	32	67.5	170
9	42	67.5	169
10	36	65	155

Vibration Apparatus & the Vibration Environment

The Boeing Human Vibration Facility (Figure 1) was used to provide the vibration for this program. The facility is that described in a previous document (reference 2) with at least two noteworthy modifications and improvements. Prior to this study there had been evidence that mechanical and hydraulic properties of the equipment were introducing distortion into the sine wave output of the vibration table primarily through table friction. Modification of the table guides to the continuous race ball type and rework of the control system resulted in a much improved system.



1. Entrance and emergency area
2. Experimental & Medical Monitoring Station (One-Way Observation Window)
3. Vibration Platform (Chair & Console Mounted).
4. Observation Area (Three One-Way Viewing Windows)
5. Equipment Operator's Station (Signal Generation, Feed back, & Monitoring).

(Separate subject preparation and interview room not shown)

FIGURE 1. BOEING HUMAN VIBRATION FACILITY

Vibration Conditions

The frequencies used in this study were the same as those used by Parks & Snyder : 1, 1-1/2, 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 23, & 27 cps. Amplitudes from zero to those necessary to produce selected acceleration limits were possible. Limits were established prior to the start of the test and were selected to avoid possible bodily harm to subjects. Since limits of physiological tolerance were not to be considered, maximum possible accelerations were set below those established by Ziegenruecker and Magid [8]. The limit utilized for each frequency used is listed in Table II.

TABLE II

Table Acceleration Limits

Frequency (cps)	Maximum "G" Possible
1	1.0
1-1/2	2.3
2	2.5
3	2.0
4, 5, 6, 8	1.5
10	1.9
12	2.25
14	2.6
16 - 27	3.0

Vibration Fidelity

Fidelity of the vibration input to the subjects can be considered as excellent. Displacement wave forms were indistinguishable from superimposed pure sine waves at each frequency, with acceleration wave forms near perfect at and above 16 cps. From 1 through 5 cps acceleration waves showed distortion generally less than 2% and from 6 through 14 cps in the range of 3 to 15%. For reference purposes sample acceleration wave forms at each frequency are included in Appendix A. Superimposed sine waves are shown for comparison. Displacements are in terms of double amplitude (DA).

Test Configuration

An illustration of the overall test station configuration is shown in Figure 2. A specially designed seat was utilized to provide proper subject position, with reinforced plywood inserts covered with approximately 3/4 inch hard felt used in preference to seat cushions or parachute packs to assure fidelity of the vibration received by the subject. For back support an adjustable 4 x 8 inch felt covered support was provided near the region of the first lumbar vertebra (Figure 3). The support proved not only extremely comfortable but also elicited a natural response of sitting erect. A felt covered adjustable foot rest was also provided which permitted adjustment of each subject to the desired seating position. Subject restraint was provided by a single lap belt, the tension of which could be set at any desired level (Figure 4). Thirty pounds was used throughout this test.

The subject display and controls used in the program are shown in Figures 5 & 6. The display contained the four descriptive terms referencing the levels to be established which could be illuminated separately as required by the experiment, and "up" and "down" arrows which provided feedback indications to the subject concerning his control action in increasing or decreasing vibration amplitude. Amber illumination of either arrow indicated "slow" change (80 seconds from 0 to maximum amplitude) and white illumination referred to "fast" (40 seconds for total travel). The remaining portion of the display remained lighted at all times during the test to provide the subject illumination required for monitoring by the attending physician (Figure 7).

The only controls utilized by the subject consisted of pistol type hand grips held in each hand. Each grip contained a three position "trigger" switch at the index finger location and a thumb switch located on top (Figure 6). Depression of the right or left hand trigger switches respectively, increased or decreased vibration amplitude, moderate depression producing the slow rate of change and hard depression evoking the fast. In each case, the appropriate indication appeared on the subject display. When neither switch was being activated the amplitude remained constant, and in the event of simultaneous depression, the "down" command automatically took precedence. The right hand thumb switch was used by the subjects to indicate when an indicated subjective level was matched by the existing vibration and served both to notify the experimenter of such a match and to automatically record, via oscillograph, the acceleration being produced. The left thumb button

FIGURE 2 EXPERIMENTAL TEST STATION CONFIGURATION

FIGURE 3 ADJUSTABLE BACK SUPPORT

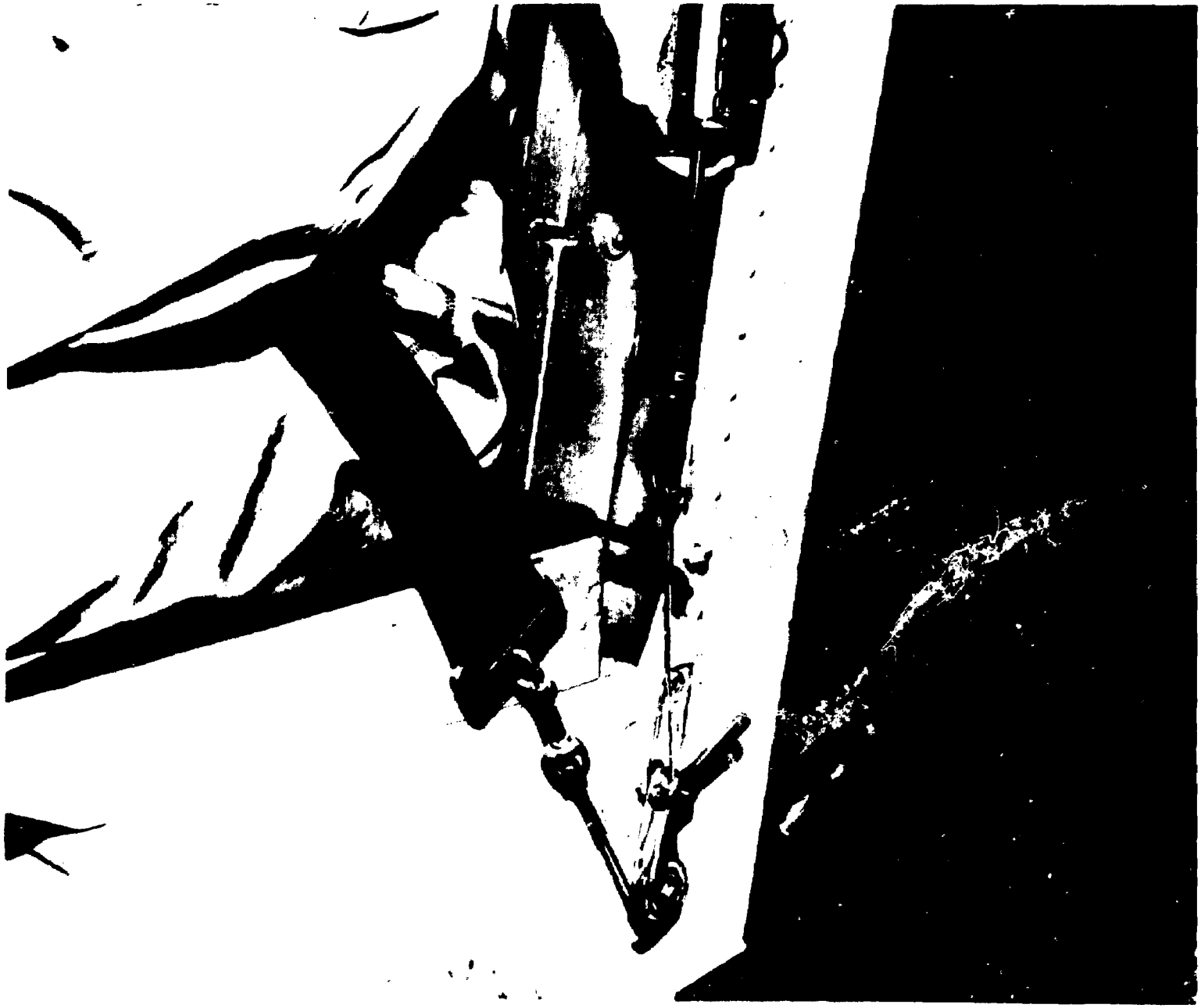


FIGURE 4 RESTRAINING BELT ADJUSTMENT

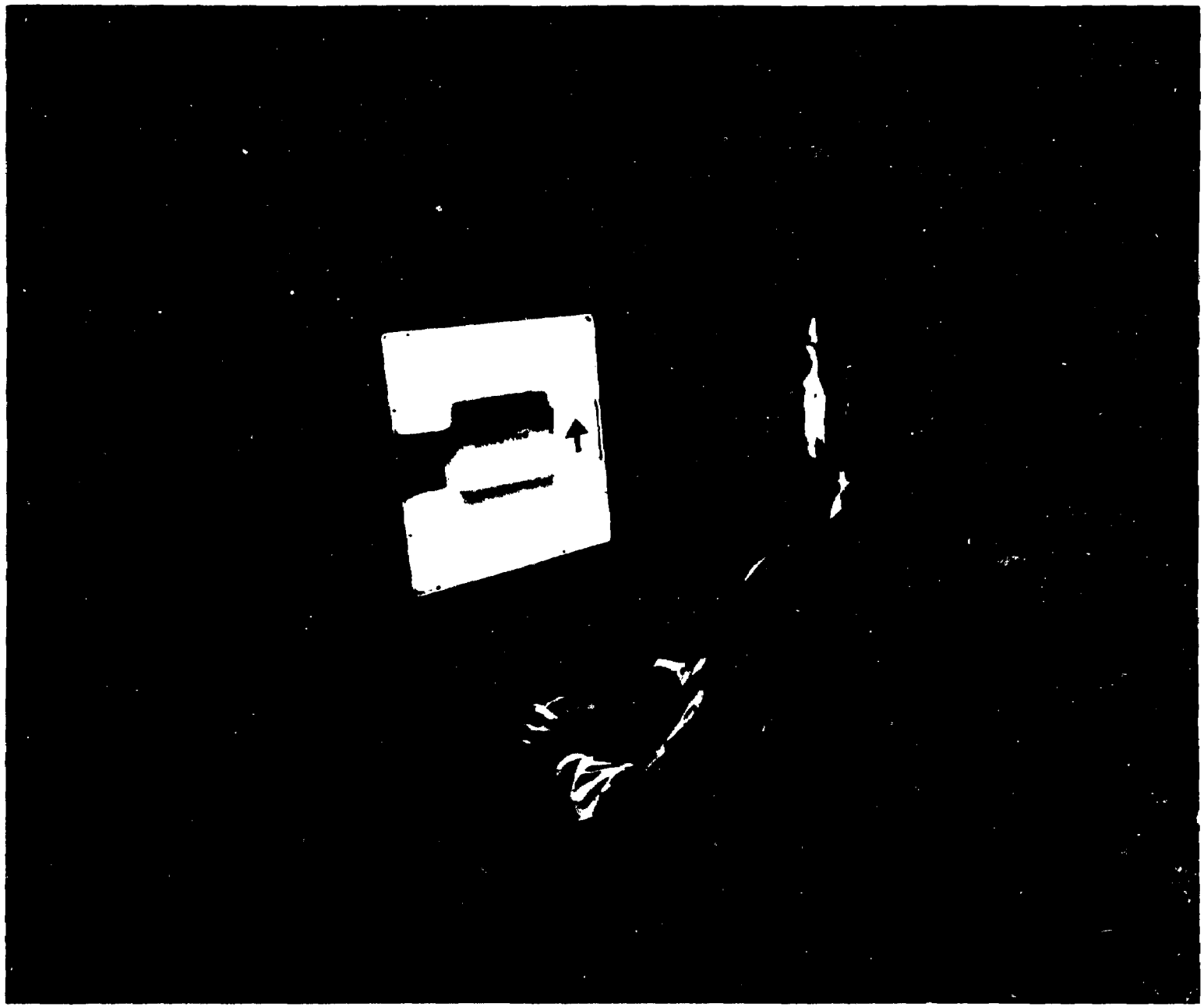


FIGURE 5 SUBJECT DISPLAY CONSOLE

FIGURE 6 VIBRATION CONTROL HANDLES

FIGURE 7 SUBJECT ILLUMINATED BY PANEL

was a cut-off switch and if pressed for any reason would immediately stop all vibration. Use of this switch was not required on any test during the reported program. Switches were color coded to preclude inappropriate actuation.

Control of the command indications given subjects, communication control between subject, experimenter and equipment engineer, and monitoring of subject pulse, EKG, and table acceleration were accomplished at the experimenter-physician station (Figure 8). Data recording and equipment set-up were performed at the equipment operator's station.

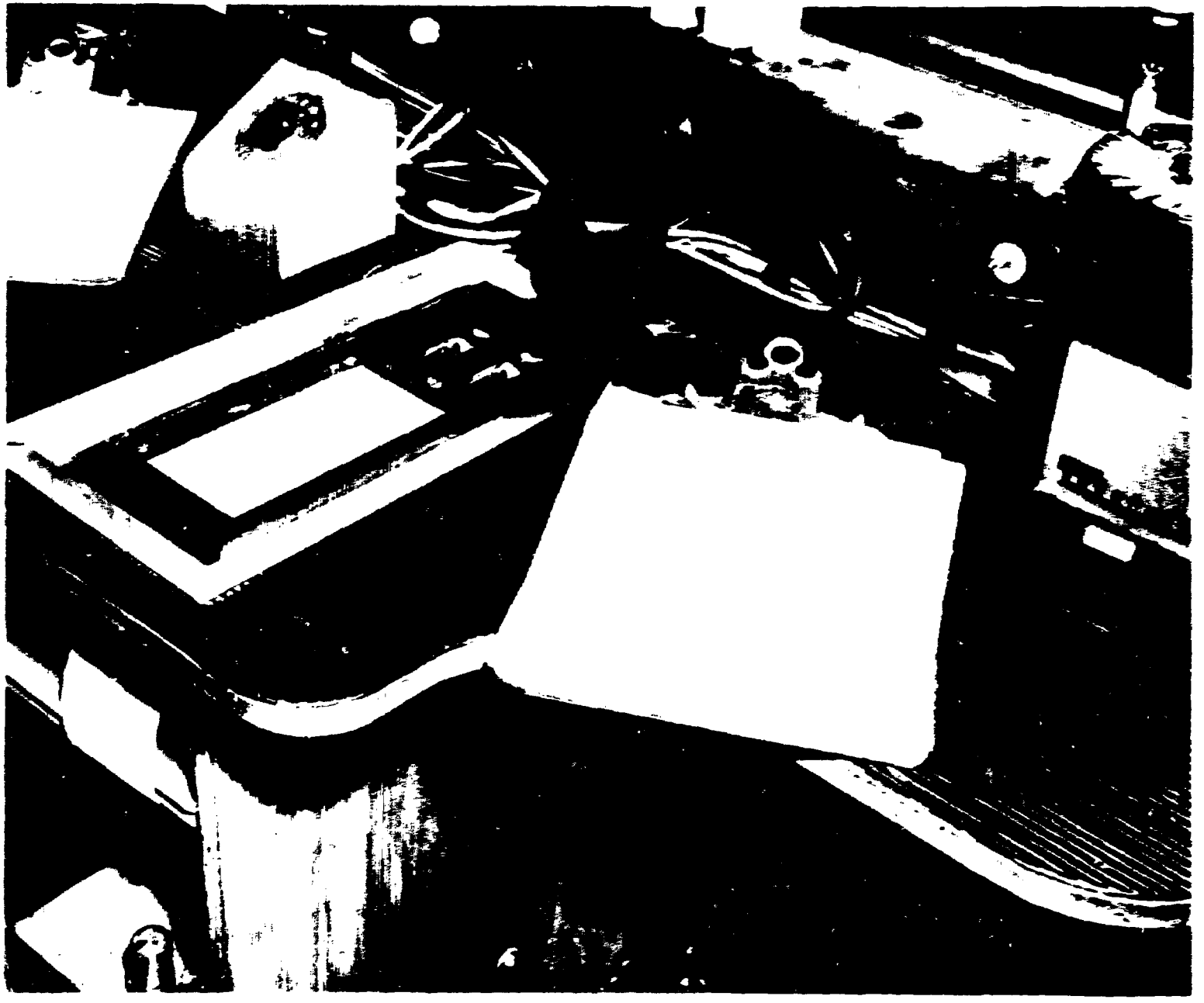


FIGURE 8 EXPERIMENTERS STATION

Testing Sequence and Procedure

Approximately one week prior to the start of testing, experimenters and the principal investigator met with subjects to define and orient all involved personnel with the program, its purpose and individual responsibilities. Copies of initial subject instructions (Appendix B), program schedules, and subjective level definitions were provided subjects at this time.

In the test program all subjects were given nine sessions during each of which eight levels (each of the four subjective levels two times) were identified at each of four vibration frequencies. The first test session for each subject was used for familiarization to procedures and the facility, with data not utilized. The remaining eight were divided into two test series. Each series provided two readings of all levels at each of the sixteen selected frequencies. Frequency presentation and level establishment sequences were randomized and counter balanced in all cases.

An experimental session was comprised of the following sequence of events:

(1) The subject was given a pre-test physical examination.
(2) Electrocardiogram contacts and leads were attached to the subject.
(3) Subject donned flight coveralls and took his position in the facility.
(4) Restraining belt was set at the prescribed tension and EKG leads were connected.
(5) Instructions and level definitions were read to the subject.
(6) A group of four tests (four frequencies) and de-briefings was administered.
(7) Subject was given a post-test physical, coffee and doughnuts, a composite de-briefing and was dismissed for the day.

A given test sequence (step 6) involved the establishment of each of the four subjective vibration levels twice at a preselected frequency. The subject, when positioned and ready for the test, would be presented one of the levels through illumination of the appropriate portion of the display and would adjust the vibration severity through his controls to "match" that level. When satisfied that the vibration was subjectively equal to the definition provided, depression of the right hand thumb "event" button recorded the vibration, and cued the experimenter to indicate the next level. Approximately two seconds were involved in the data recording and new level selection process with no interruption of vibration between levels required.

Between tests, three to five minutes were spent collecting comments concerning physiological and psychological response to the vibration. Four tests were completed each session with sessions requiring approximately forty-five minutes to complete. Four sessions were scheduled each test day with the restriction that no subject encounter vibration on successive days. A physician monitored all tests.

Data Utilization

Data taken during the experiment consisted mainly of acceleration curves recorded on an oscillograph. Four channels of information were taken from accelerometers mounted on the underside of the seat surface; two vertical (at different scale factors to provide accurate readings regardless of level and for cross-check purposes); one lateral; and one longitudinal. Data from similar accelerometers mounted on the vibrating platform and continuous table position were recorded by electronic pen for back-up and additional cross check. All curves were read peak to peak and referenced to a 1 G base.

Utilization of the data was for the most part descriptive in nature. Because of a common tendency to command the table to "maximum" amplitude (pre-established safety limits) prior to the identification of higher levels at some frequencies and the consistent presence of one or two atypically high scores at all frequencies, median scores were utilized to establish subjective curves. Loss of data due to predetermined table limits precluded use of subject means. Post-test questionnaire data were used to determine the physiological effects of vibration and to assure continued subject understanding of level definitions.

RESULTS

Subjective Response Curves

The subjective curves established in the program may be seen in Figures 9 & 10. Figure 9 shows the curves on a linear scale; Figure 10 shows them with logarithmic relation to velocity, acceleration, and double amplitude. As may be seen in Figure 9, the "perceptible" level curve maintains within a margin of measurement error a constant acceleration level throughout the frequency range tested (approximately .05 g). However, the remaining levels in ascending order approach the shape of the short time tolerance curve established by Ziegenruecker and Magid [8], with differences in acceleration values between adjacent curves at any frequency above 8 cps approximately equal.

Medians and their respective 20th and 80th percentile curves for each of the subjective levels established on each of the two series of tests are shown in Figures 11 through 14. It may be seen from these Figures that vibration "experience" produces an effect primarily at levels 1 and 4. At the "perceptible" level subject variability was markedly reduced on the second series of tests and at the alarming level a considerably higher intensity of vibration was required to evoke an "alarming" response. At both "annoying" levels (2 & 3) noticeable changes produced by the prior experience were restricted to the frequency range above approximately 20 cps where slight upward shifts occurred during the second test series.

During test monitoring two apparent influences on the level of vibration selected by subjects to represent a given definition were noted: 1) the relative severity of the immediately preceeding level established (a higher response made when preceeded by a higher intensity); and 2) the relative position the identification of a particular level in the series occupied (first vs. second establishment of the level). Tests of these phenomena showed the first, i.e., the relative intensity of the immediately preceeding level to have a highly significant effect ($p < .001$) and the second, i.e., a series sequence effect to be not only non-significant but non-existent.

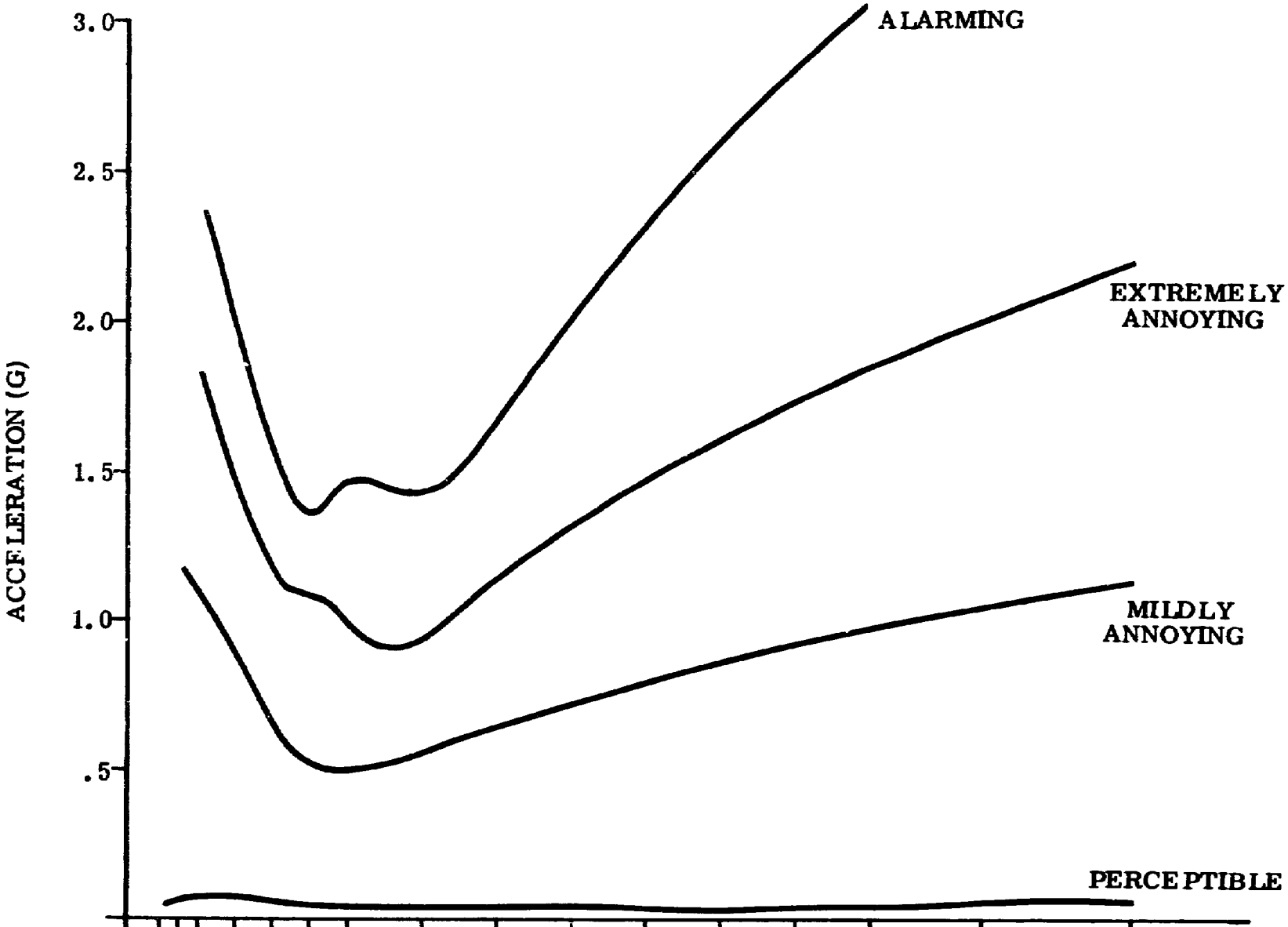


FIGURE 9

SUBJECTIVE HUMAN VIBRATION RESPONSE CURVES

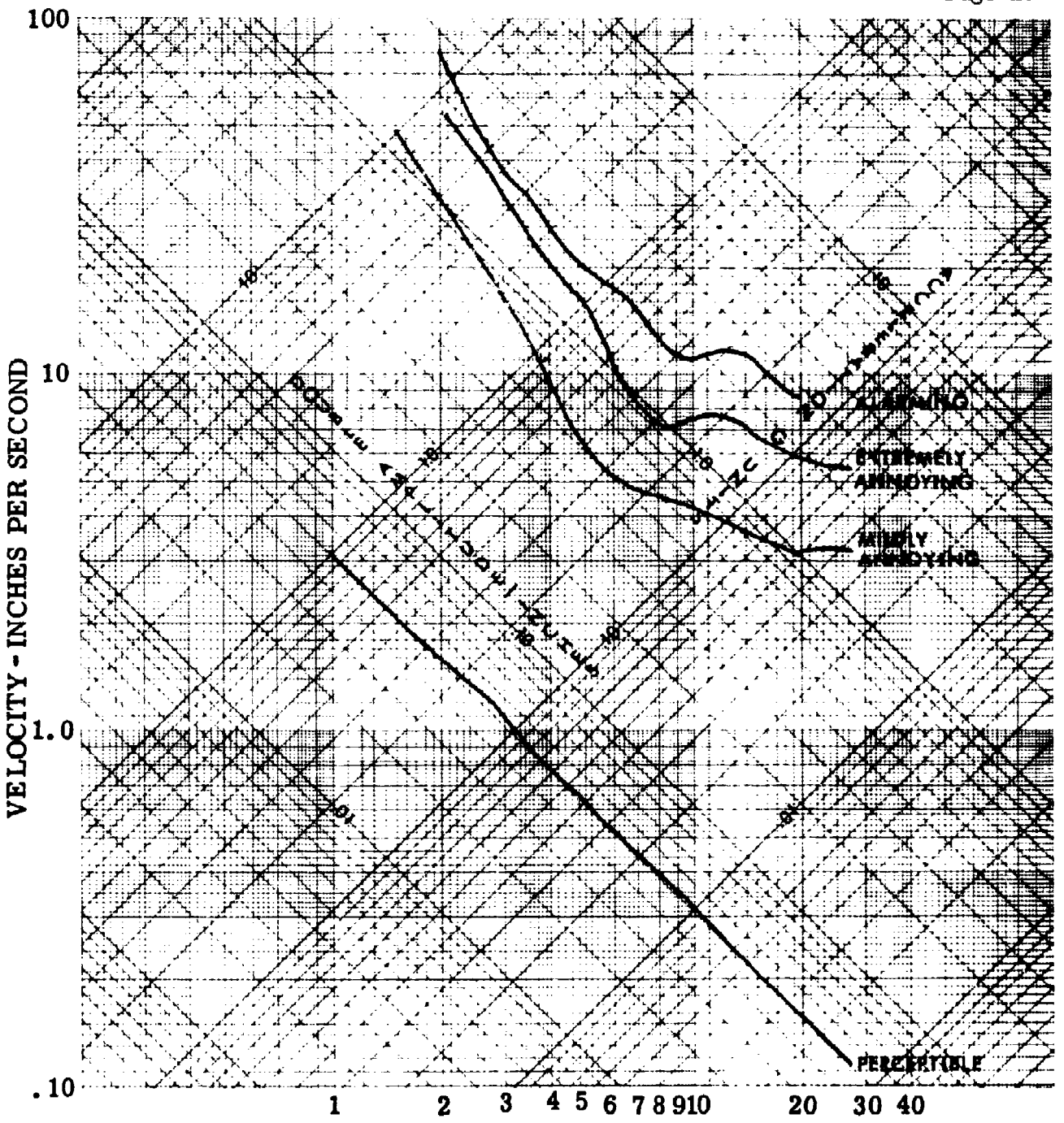


FIGURE 10

SUBJECTIVE CURVES RELATED TO VELOCITY ACCELERATION AND DISPLACEMENT

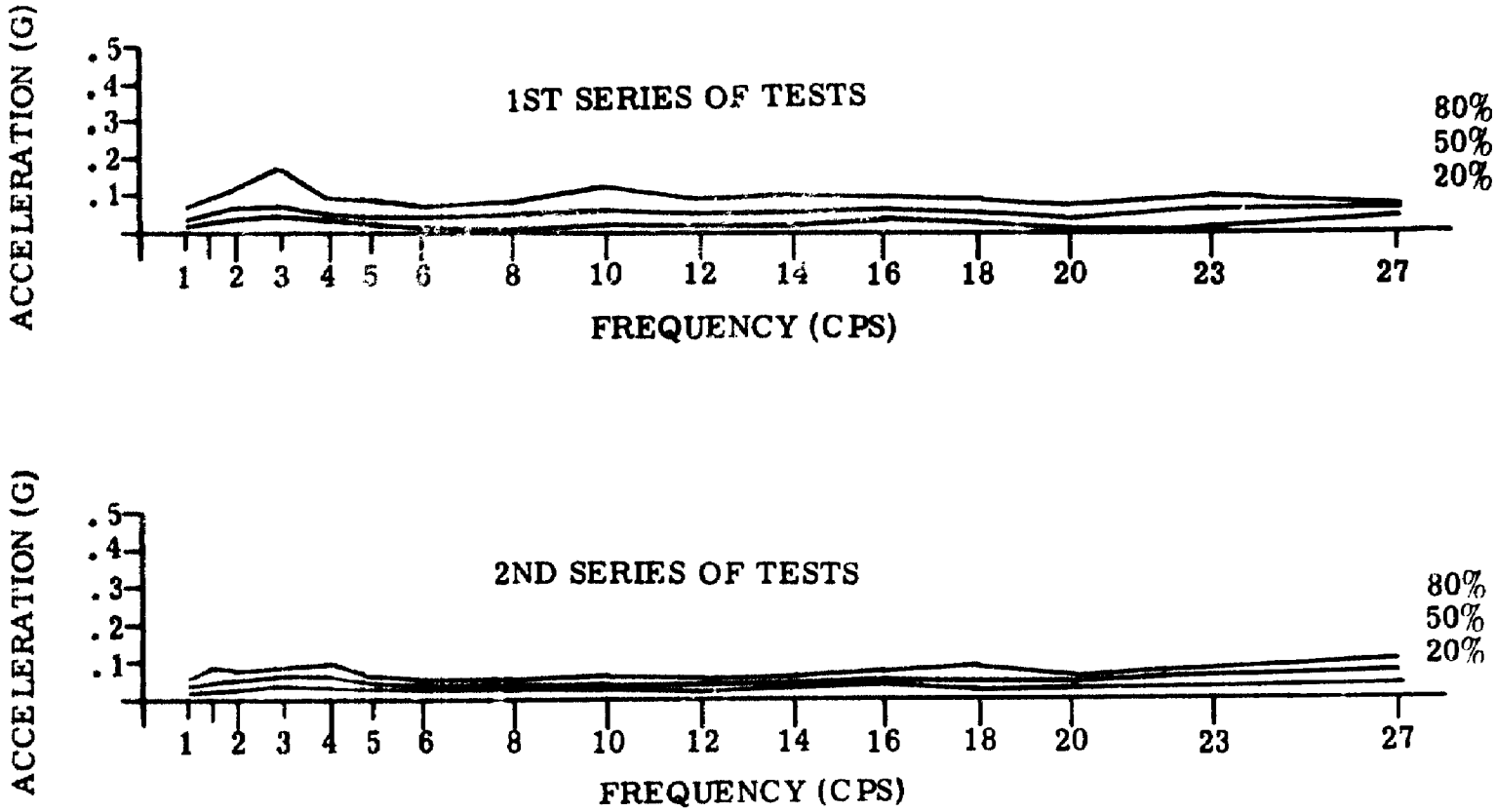


FIGURE 11

MEDIANS, 20TH AND 80TH PERCENTILES ESTABLISHED FOR PERCEPTIBLE LEVEL OF VIBRATION

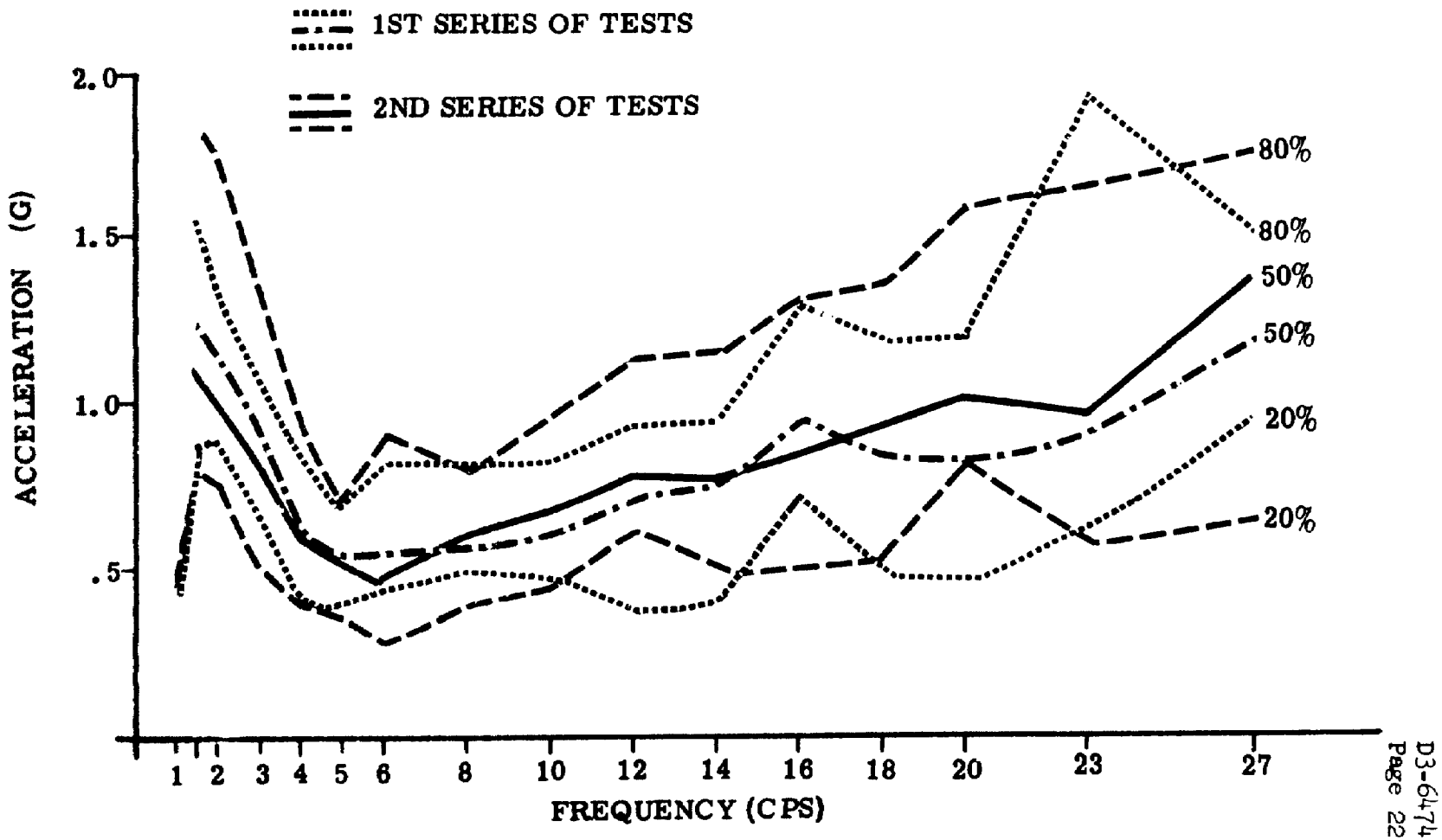


FIGURE 12

MEDIANS, 20TH AND 80TH PERCENTILES ESTABLISHED FOR MILDLY ANNOYING LEVEL OF VIBRATION

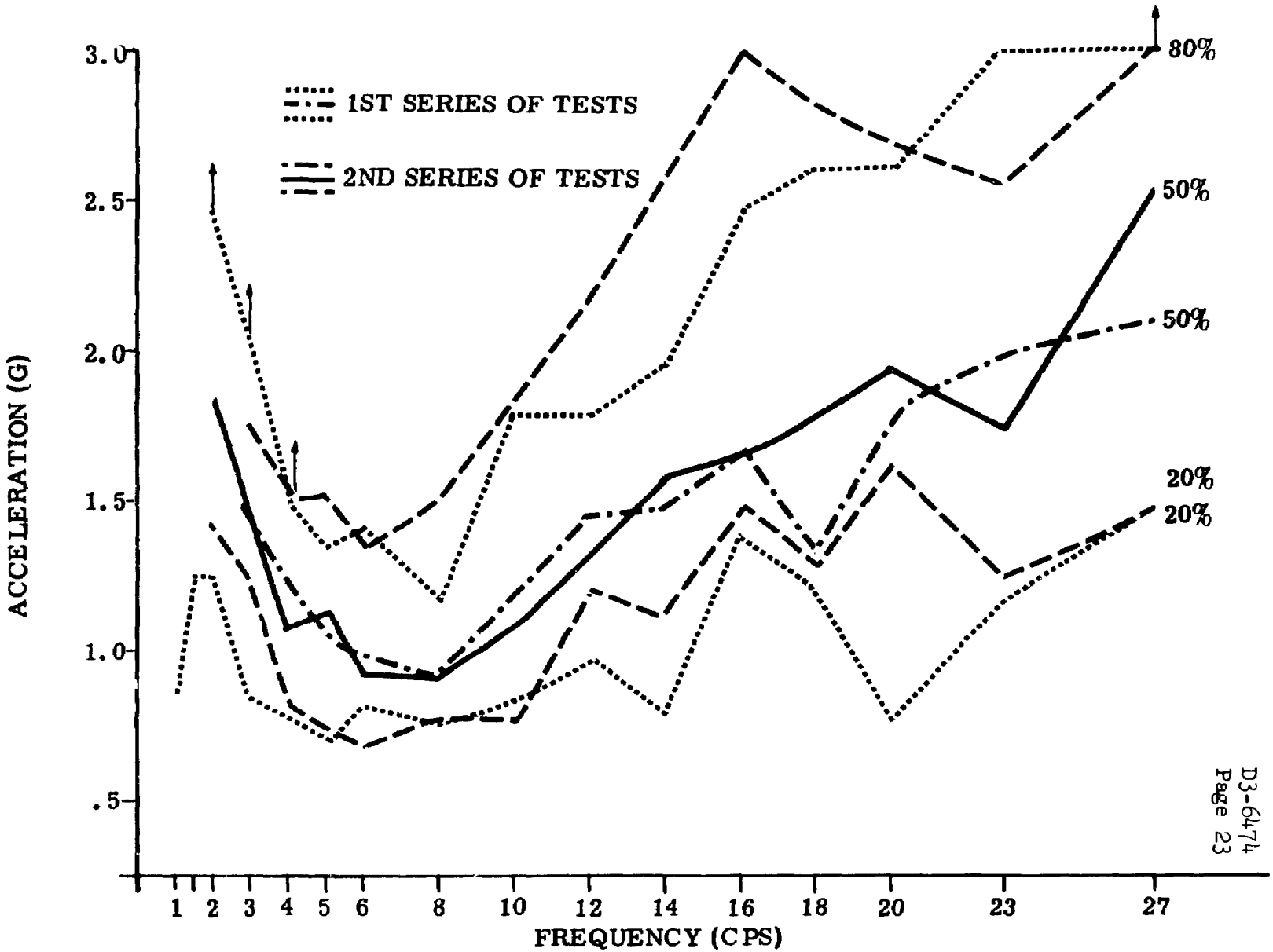


FIGURE 13

MEDIANS, 80TH AND 20TH PERCENTILES ESTABLISHED FOR EXTREMELY

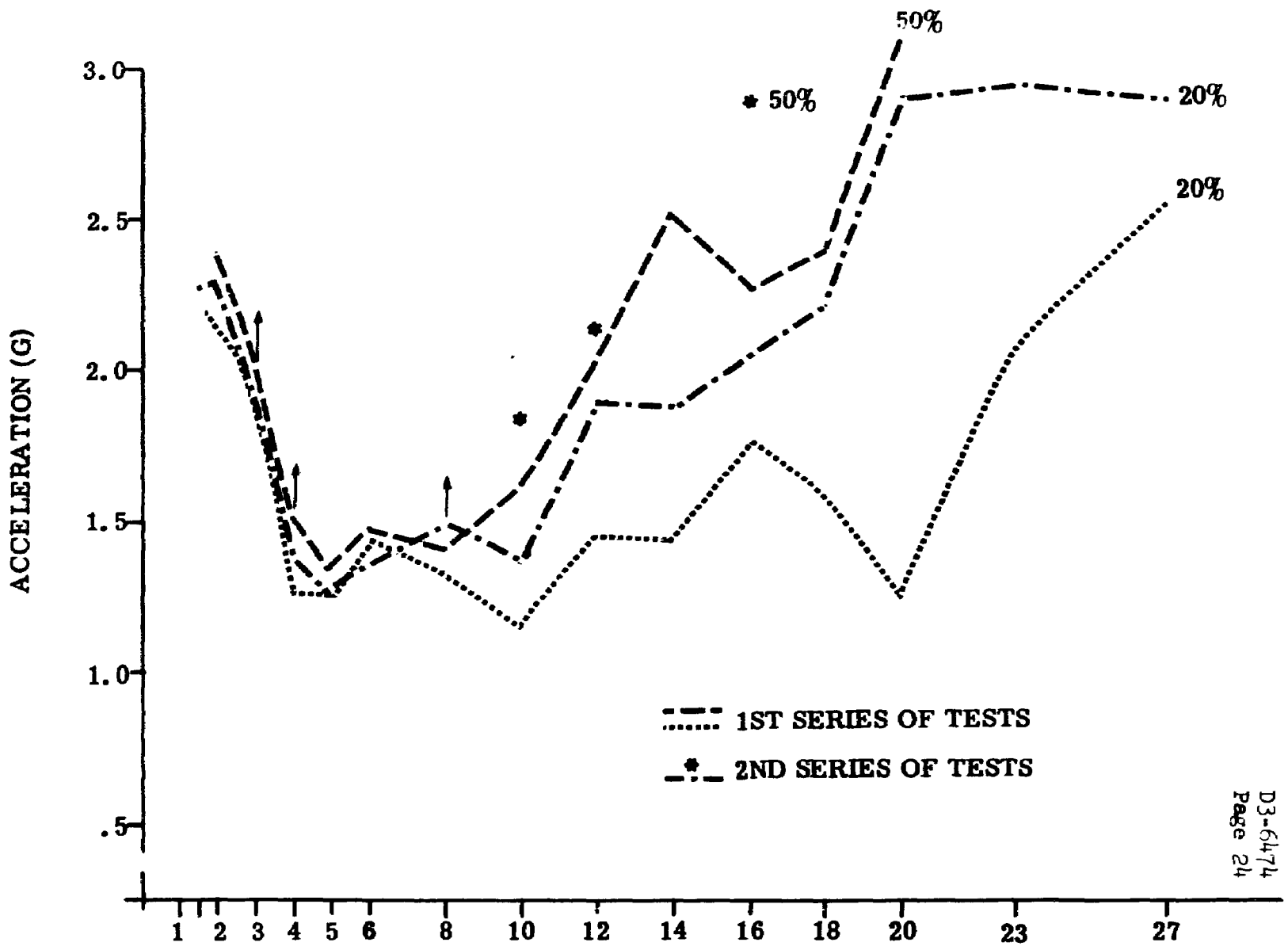


FIGURE 14
MEDIANS AND 20TH PERCENTILES ESTABLISHED FOR ALARMING LEVEL OF VIBRATION

Explanation of the difference which proved significant can immediately take two forms: 1) that the direction from which a level is approached is responsible; and 2) that the subjects frame of reference is varied as a function of the immediately preceeding vibration level encountered. With the method of vibration control utilized in this program preference is for the second of the possible explanations. Subjects had the prerogative in these tests of approaching any level of vibration from either direction merely by going "through" the specified level by means of the controls provided, reversing the control and approaching from the opposite direction. Most subjects, did in fact, apparently prefer to approach all levels from lower amplitudes or by use of self-established bracketing techniques. (No cues concerning a preferred method were provided by the experimenter). A frame of reference concept on the other hand, similar to Helson's "adaptation level" theory [1], seems both plausible and appropriate to the type of perception required by this study and would adequately account for the noted variations of subjective experience.

Comparisons of the curves established in this program with those of similar research are shown in Figures 15 through 18. An unexpected drop in the "perceptible" level at the low end of the curve becomes apparent on the logarithmic scale of these figures. This drop is probably due to the detection of vibration harmonics present at the low levels of the 1, 1-1/2, and 2 cps frequencies. (See Figures 20, 21, and 22, Appendix A).

Figure 15 shows the relationship of the curves to the short time, one minute and three minute tolerance curves of Ziegenruecker, Magid, & Coermann [5, 8]. As is evident in the illustration, the subjective response curves approach the shape of the short time tolerance curve as intensities and the corresponding judgements increase. Also, it should be noted that both subjective levels 3 & 4 (extremely annoying and alarming) at certain frequencies have acceleration levels higher than those established previously as one and three minute tolerance limits. With the random presentation of levels used in the program and the average time of approximately one minute used by subjects to establish each level, most subjects actually were above the one minute tolerance level for periods in excess of that specified. The apparent discrepancy can be explained by examination of test methods. Whereas, in the Magid et al., studies subjects were subjected to a constantly increasing vibration to a preselected point at which they remained for the required duration, subjects of this study had personal control of the vibration received. If vibration became too severe, they could decrease it at will, and as such, knew at all times what levels of vibration to expect. Thus, there were no premature cut-offs and apprehension was markedly reduced.

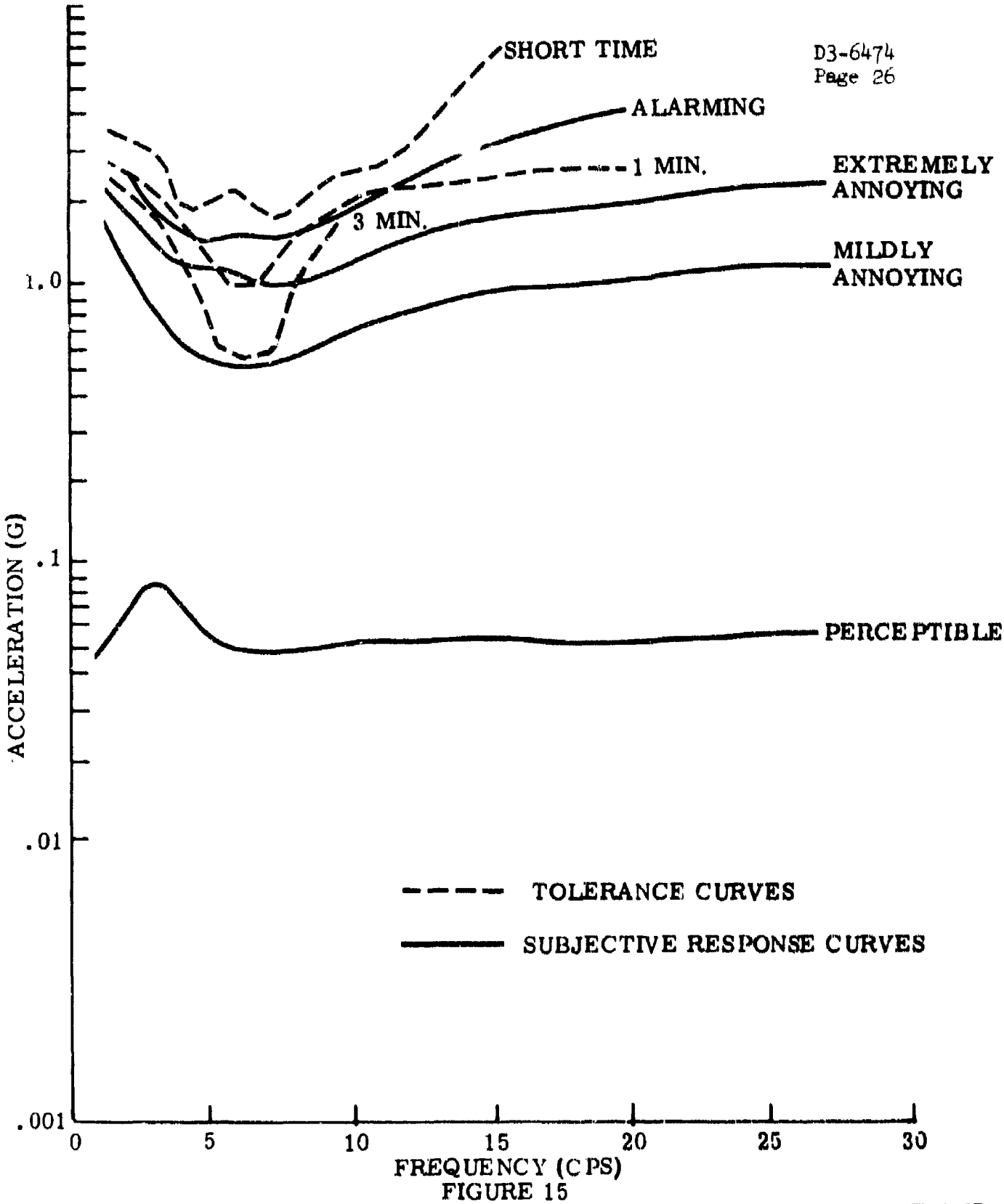


FIGURE 15

SUBJECTIVE RESPONSE CURVES COMPARED TO SHORT TIME, 1 MINUTE AND 3 MINUTE TOLERANCE CURVES OF ZIEGENRUECKER, MAGID & COERMANN (REFERENCE 5, 8)

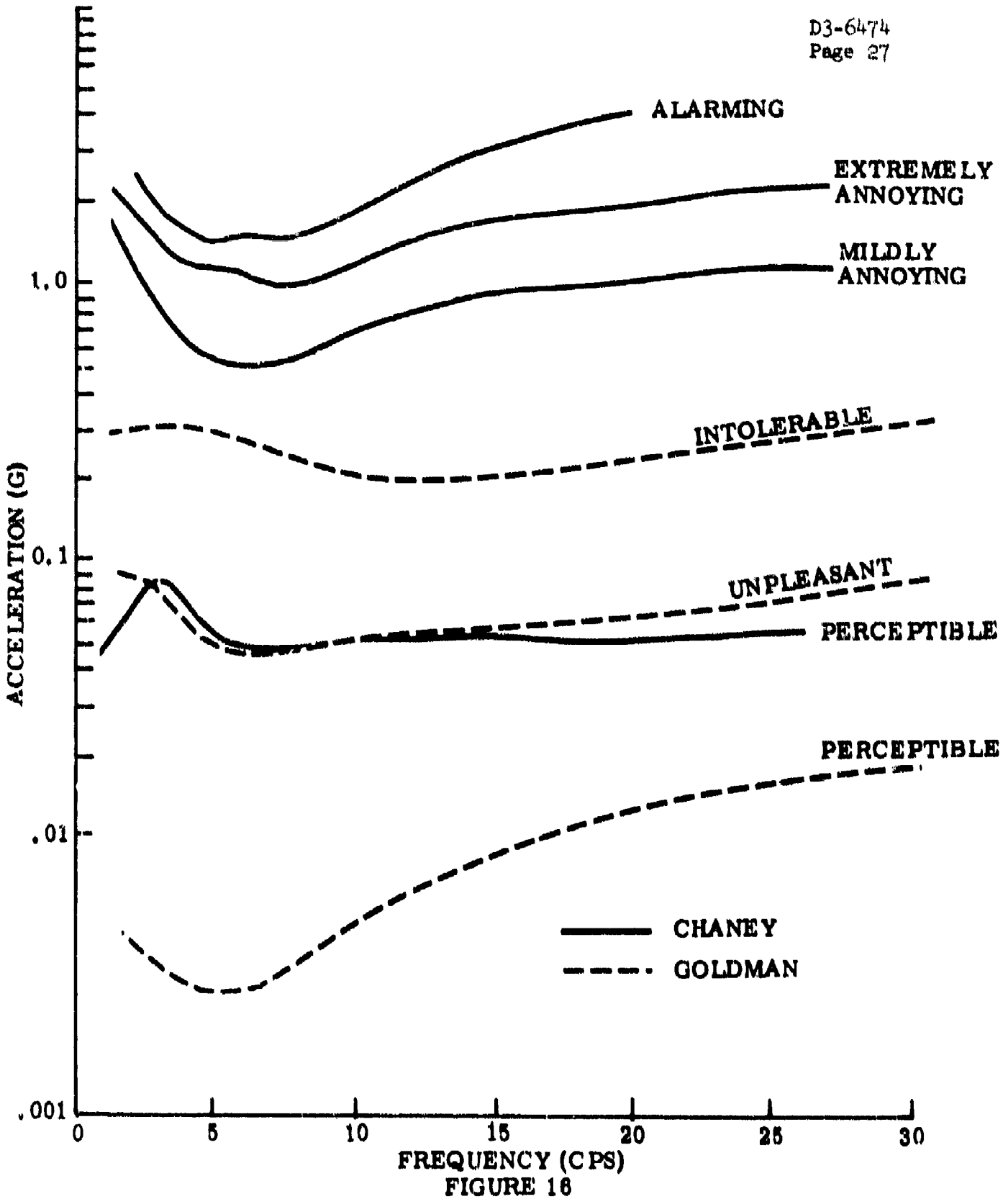


FIGURE 16

SUBJECTIVE TOLERANCE CURVES OF THIS STUDY COMPARED TO THOSE OF GOLDMAN (REFERENCE 3)

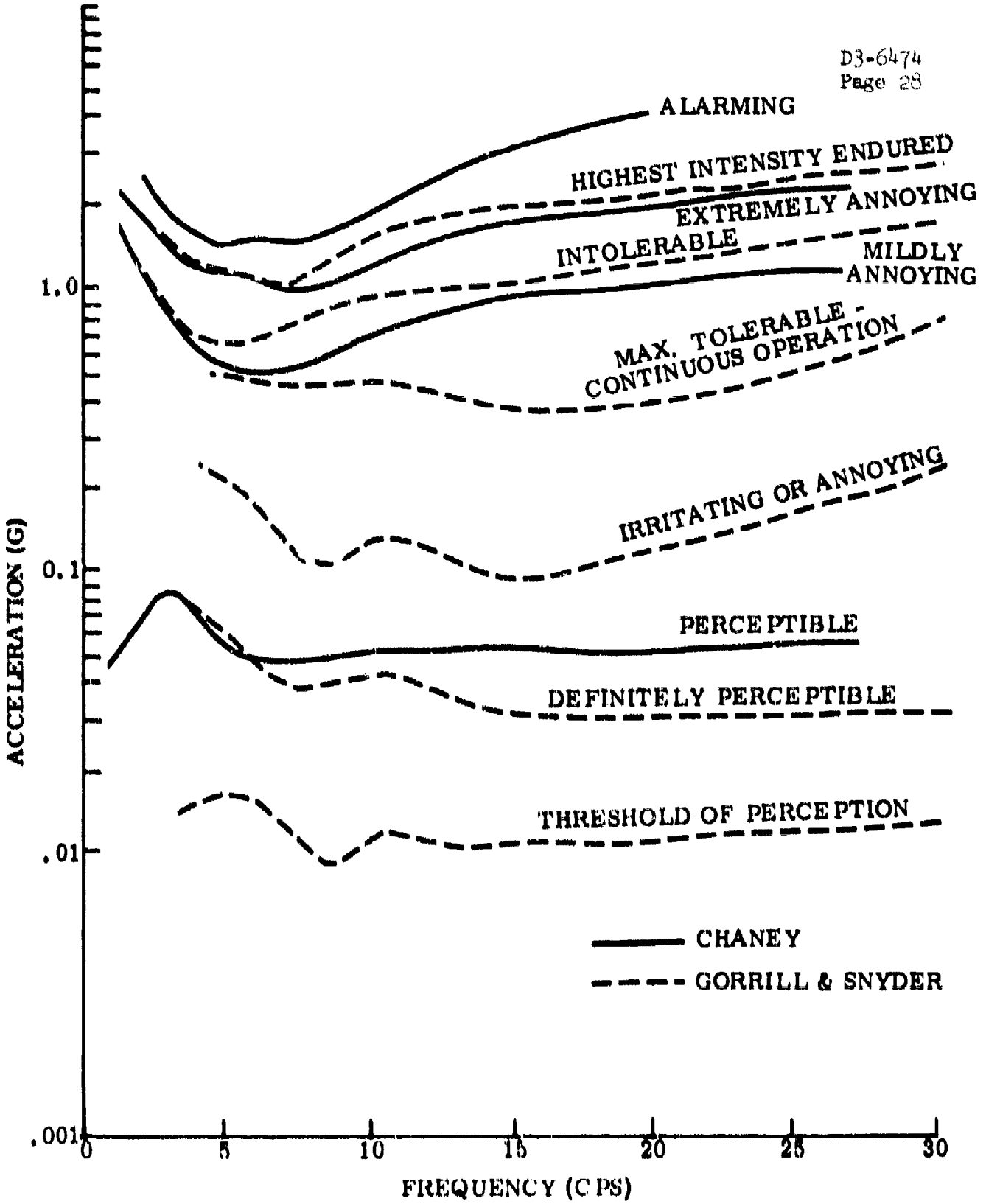


FIGURE 17

SUBJECTIVE TOLERANCE CURVES OF THIS STUDY COMPARED TO THOSE OF GORRILL AND SNYDER (REFERENCE 4)

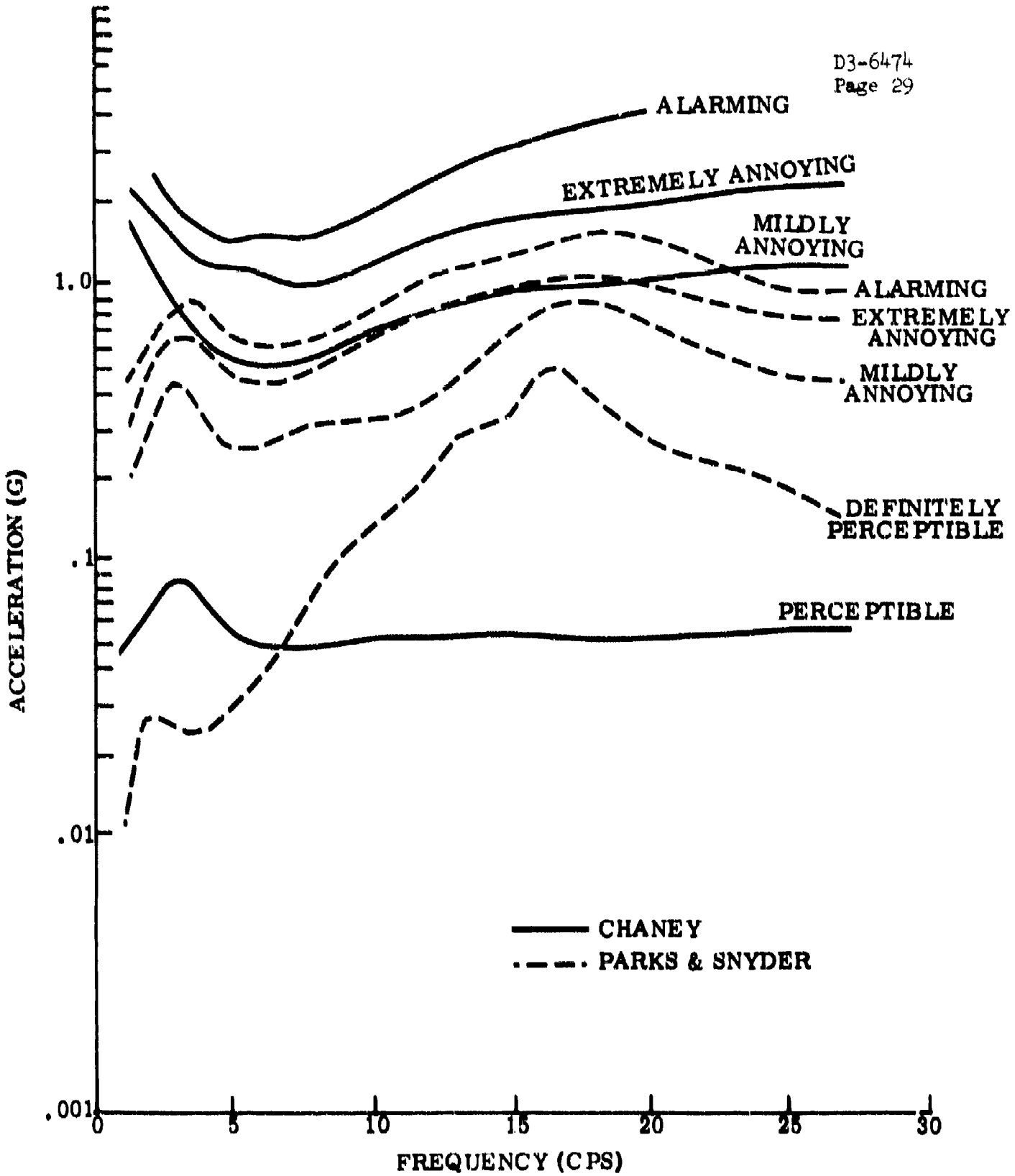


FIGURE 18

SUBJECTIVE TOLERANCE CURVES OF THIS STUDY COMPARED TO THOSE OF PARKS AND SNYDER (REFERENCE 7)

Figure 16 shows the response curves in comparison to those of Goldman [3]. In all cases, the curves derived in this program are displaced significantly upward from those assimilated from other sources in Goldman's report. Reasons for the differences can not be definitely stated, however, several logical possibilities are present.

Initially, the subjects of this study were isolated from the vibration platform, both at the body and foot contact points, by 3/4 inch hard felt and were denied visual reference to the non-vibrating environment. Also, subjects were instructed to reference the levels established only to a personal reaction to the vibration itself, purposefully disregarding reference to riding comfort or an operational situation. And again, subjects had individual command over the vibration inputs. Lack of any of these experimental conditions was found in preliminary tests to unnecessarily reduce individual estimates of the desired vibration effects.

Comparisons of the curves with similar ones derived by Gorrill and Snyder [4] and Parks and Snyder [7] are shown in Figures 17 & 18. Again, the curves of this program are above those of the other studies, both of which employed an operational situation in the curve derivations (heavy military type control wheel and column). This fact is probably the predominant factor producing the noted differences with the other experimental conditions mentioned in the previous discussion as additional possibilities.

Physiological Effects

A summary of physiological sensations experienced by subjects in the program may be seen in Figure 19. Solid lines indicate areas of slight pain and dashed lines indicate a composite of other effects, i.e., itch, pressure, tightness, etc. Little need be said concerning these effects since they correlate closely with similar findings of the Magid & Coermann [5], Mandel & Lowry [6], and Parks & Snyder [7] studies. One exception to the rule, however, seems worthy of mention; the consistent report by two subjects of slight vertigo at 27 cps. The actual sensation experienced is best expressed by the "power on stall to the left" phrase used by one of the subjects in his explanation. In no case was the sensation so strong that an accompanying loss of orientation or onset of nausea occurred.

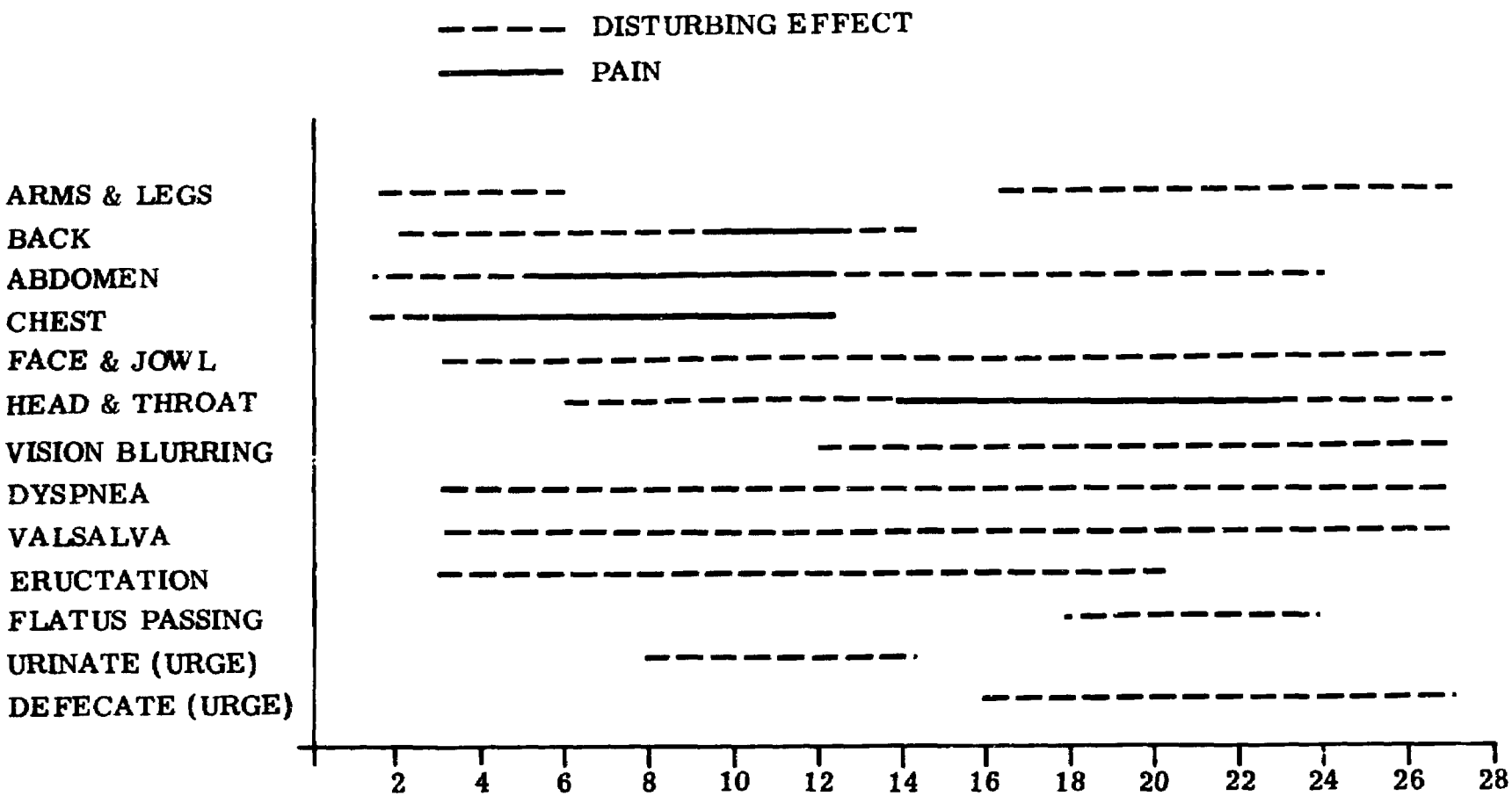


FIGURE 19

PHYSIOLOGICAL SENSATIONS EXPERIENCED

As for the remaining responses, the characteristic shift of effects upward in the body as frequency increases is present, as are the typical problems of gas exchange and retention. None of the effects encountered remained beyond a few minutes after individual test completion.

SUMMARY AND CONCLUSIONS

Goldman, Ziegenruecker & Magid, Magid & Coermann, Gorrill & Snyder, Mandel & Lowry, and Parks & Snyder have all established curves reported to be representative of man's psychological or physiological reaction to the vibration environment and yet each set of curves, although in agreement as to critical frequencies, varies significantly from its counterparts in absolute value. This research program was conducted in an attempt to delineate and resolve some of the differences of these studies through specification of possible contributing factors and the use of identifiable experimental controls.

Preliminary studies were conducted to determine the effects of numerous environmental factors and experimental techniques on the subjective reaction to vertical vibration. Results of these tests were utilized to eliminate or minimize identified adverse intervening variables in a final study which established four subjective reaction levels; perceptible, mildly annoying, extremely annoying, and alarming, in the range of 1 through 27 cps.

Subjective levels identified are generally at higher acceleration values than those of previous studies. Possible reasons for the differences including the contributions made by results of preliminary studies are discussed. Also, individual values established at a given subjective level are shown to be influenced by the magnitude of the immediately preceeding vibration level. Physiological effects, in the main, correlate with previous findings.

At least two findings in addition to the expected results of the program become evident in review of the research effort.

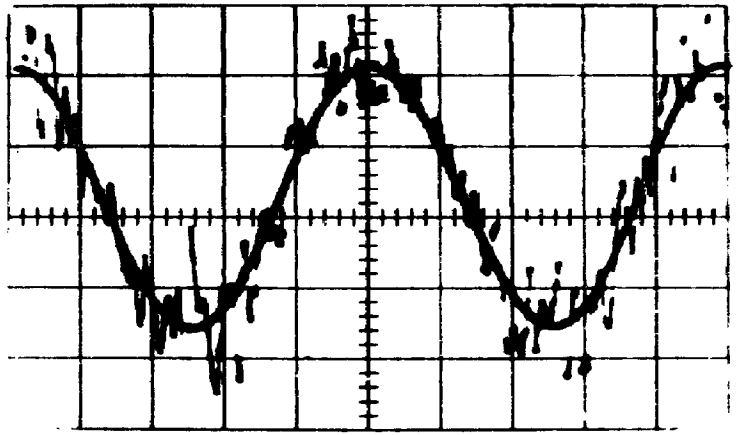
1) Preliminary tests prove of inestimable worth to an experimental program. In this study, lighting method, auditory cues, seating position, restraint method and force, and method of vibration control were all found to vary considerably the dependent variable with no change in the independent. A much higher degree of confidence can be afforded program findings as a result of this relatively small additional effort expended prior to the start of the final tests.

2) Detailed experimental and control techniques must be reported if results in an area are to be expected to correlate with similar research findings. Even valid results are impossible to interpret without the specification of possible intervening variables and the control conditions under which they

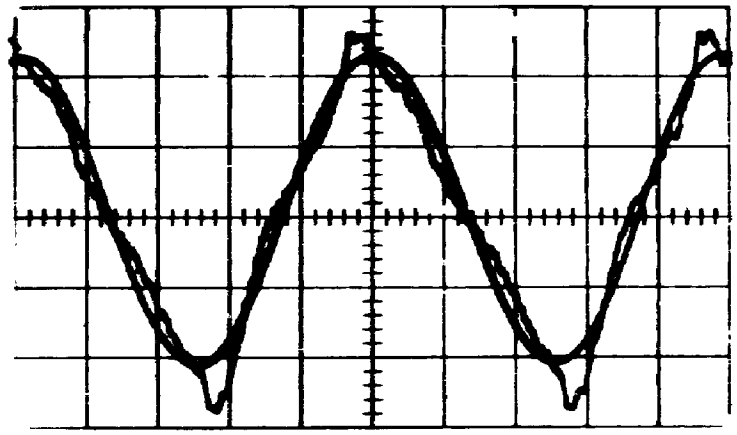
were obtained. Of particular importance in vibration research is the vibration input actually received by the subjects of the study. Definition by merely frequency and acceleration (or displacement) are insufficient. Variations in wave form, and system "noise" in form of harmonics of the fundamental frequency, can have appreciable effect upon the individuals reaction to the vibration. Sample acceleration curves of each of the test frequencies used in this program are included in Appendix A.

APPENDIX A

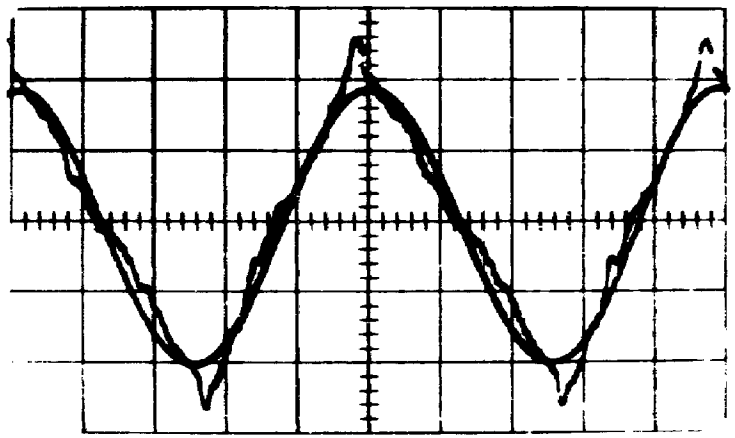
TABLE ACCELERATION WAVE FORM SAMPLES



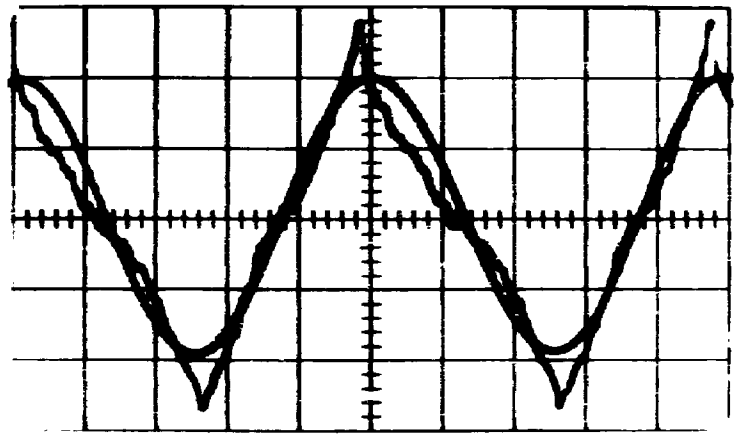
.213" DA



3.6" DA

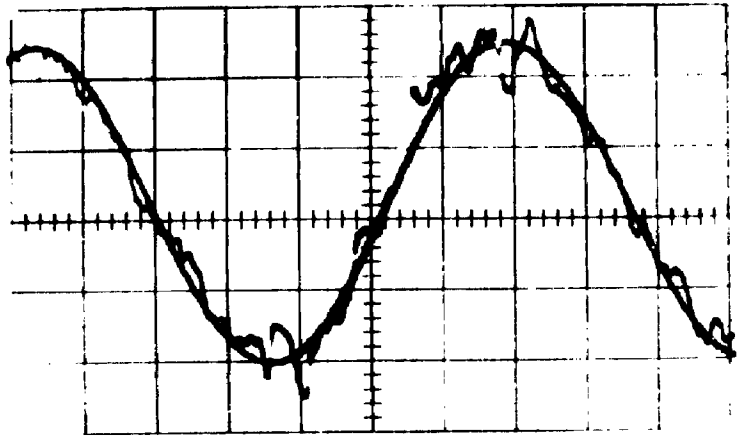


5.656" DA

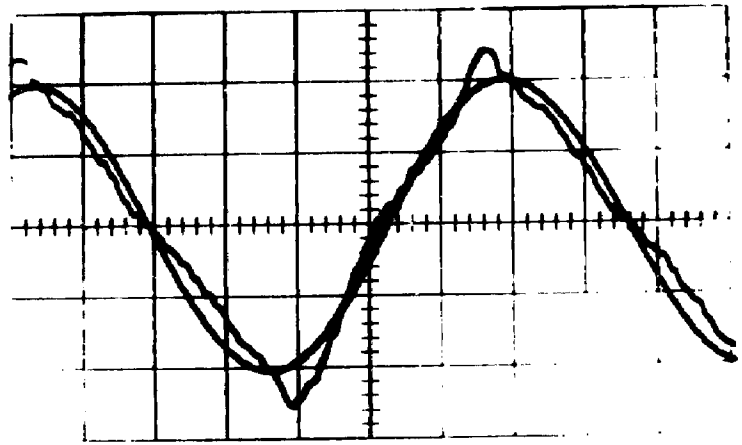


10" DA

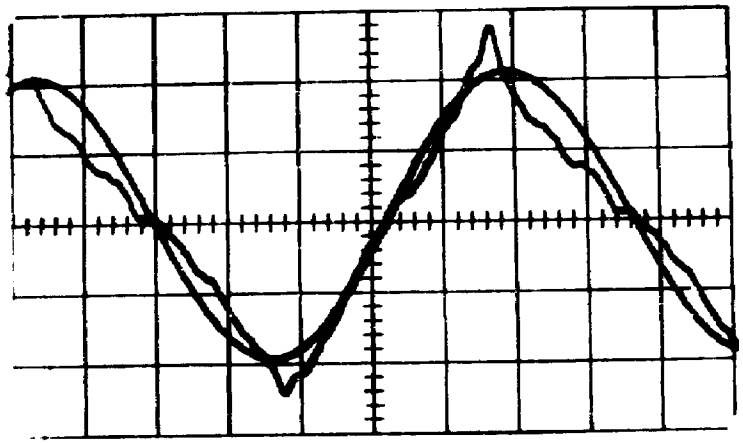
FIGURE 20 1 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS



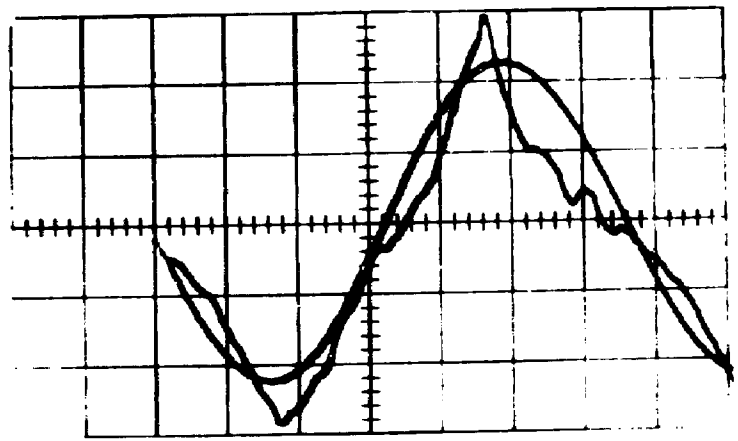
.233" DA



2.574" DA

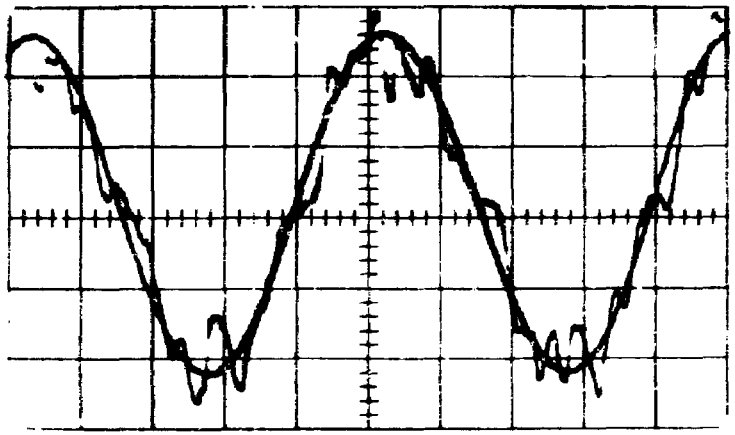


5.792" DA

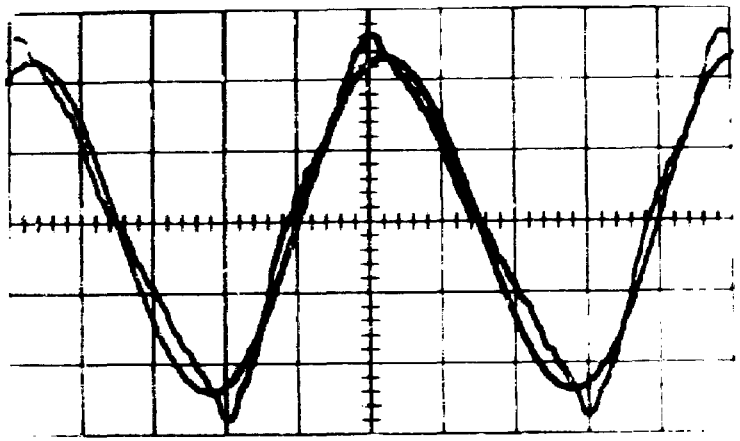


8.000" DA

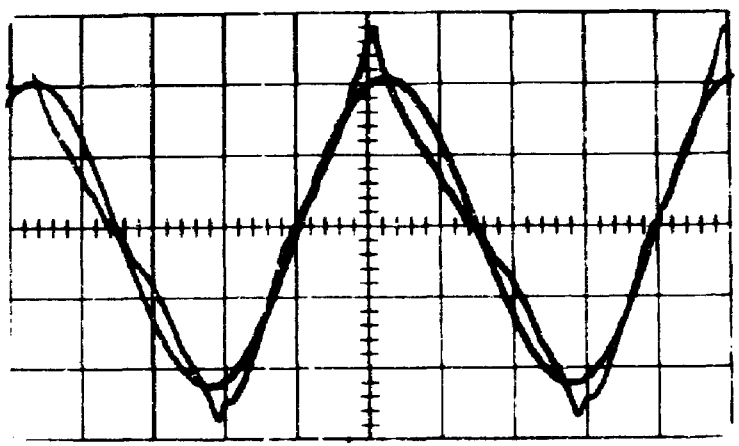
FIGURE 21 1-1/2 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS



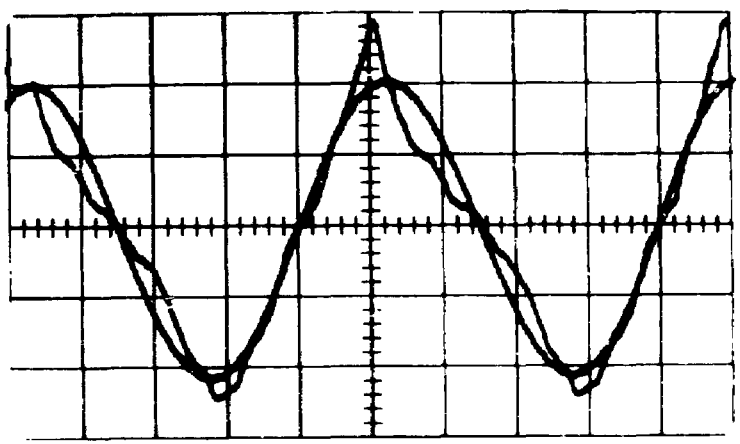
.156" DA



1.477" DA

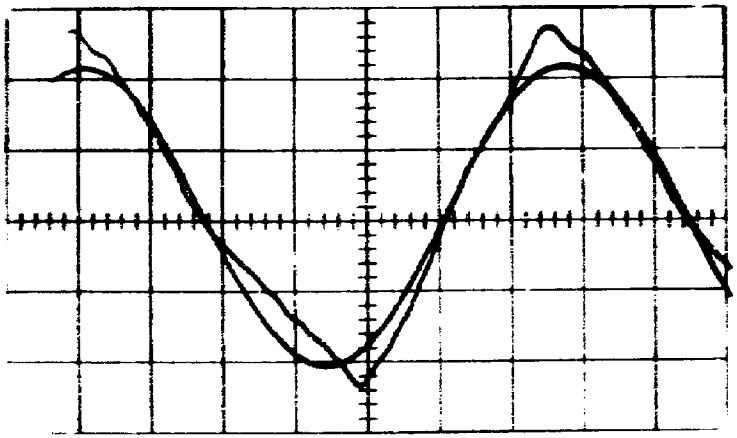


3.630" DA

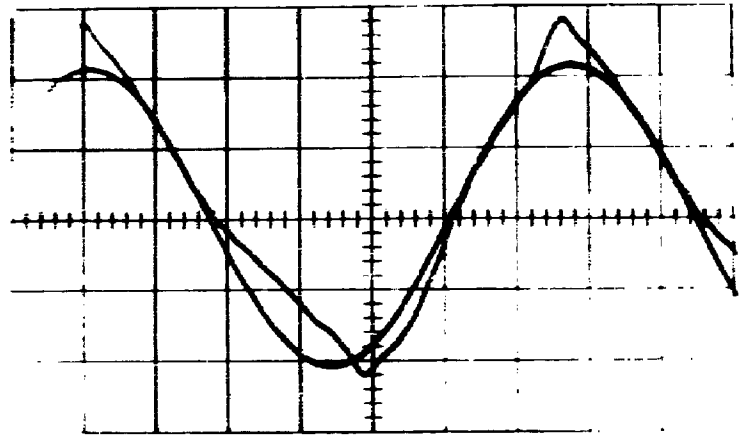


5" DA

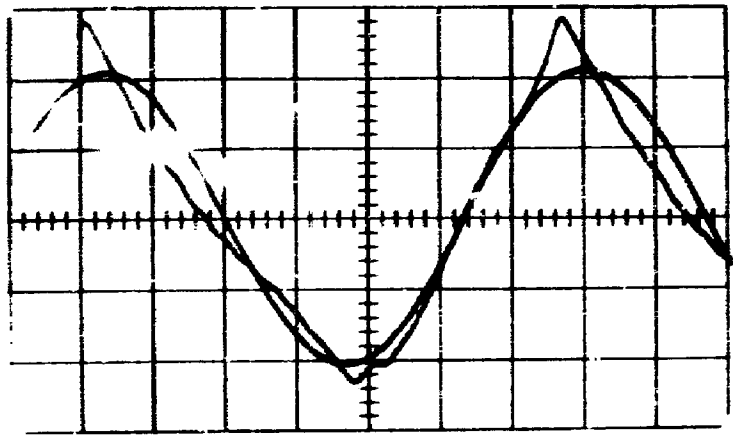
FIGURE 22 2 CPS ACCELERATION CURVE - SINE WAVE COMPARISONS



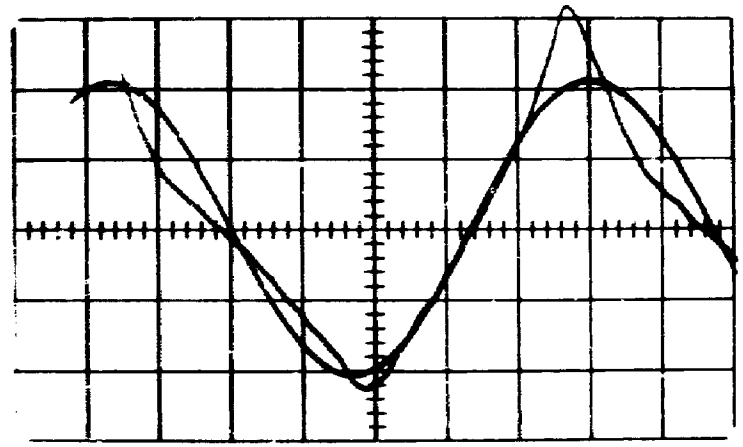
.942" DA



1.246" DA

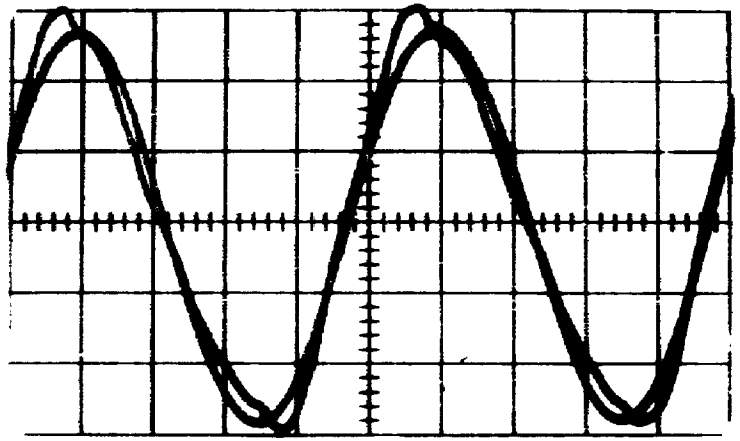


1.962" DA

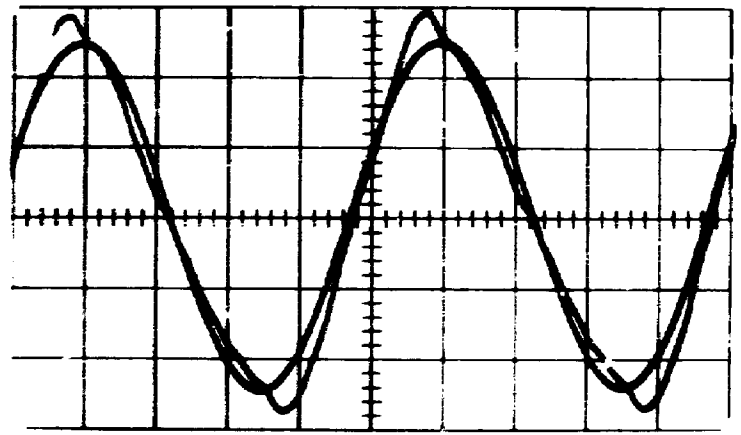


3.000" DA

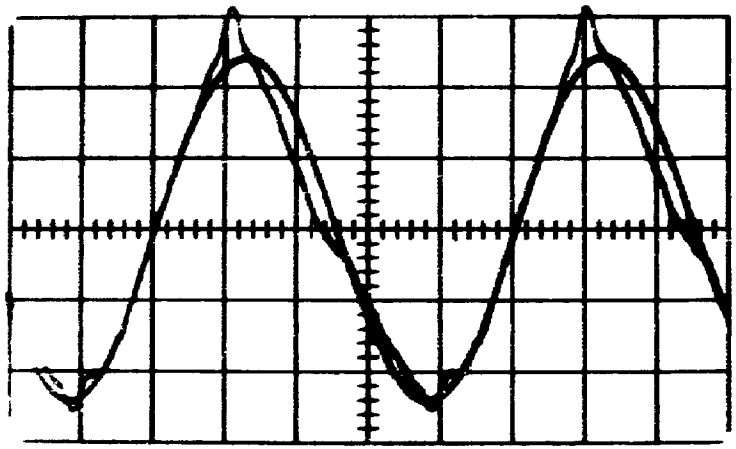
FIGURE 23 3 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS



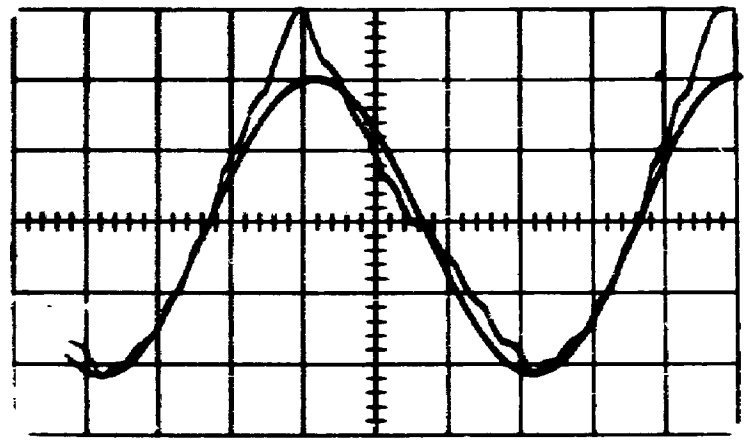
.370" DA



.554" DA

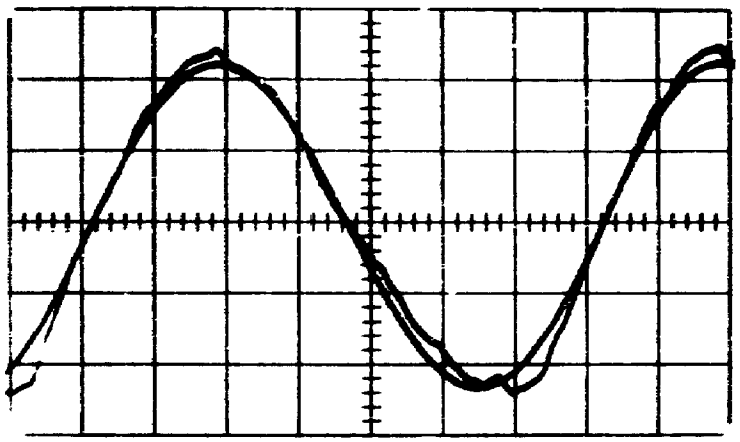


1.25" DA

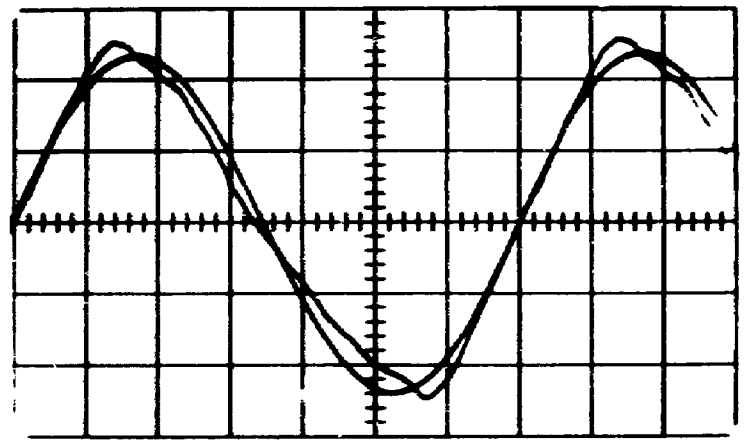


1.47" DA

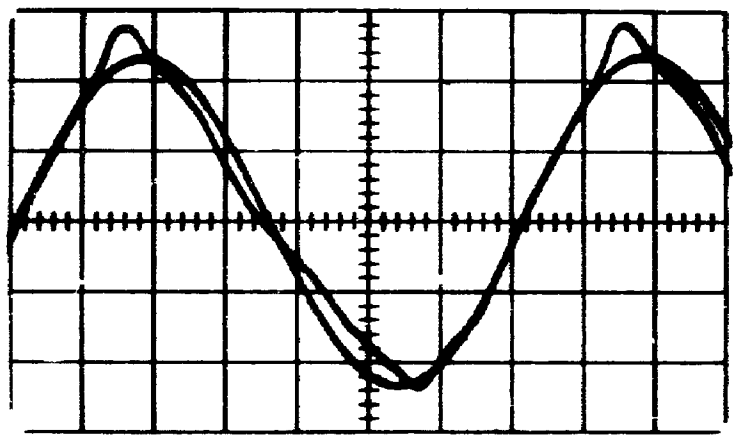
FIGURE 24 4 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS



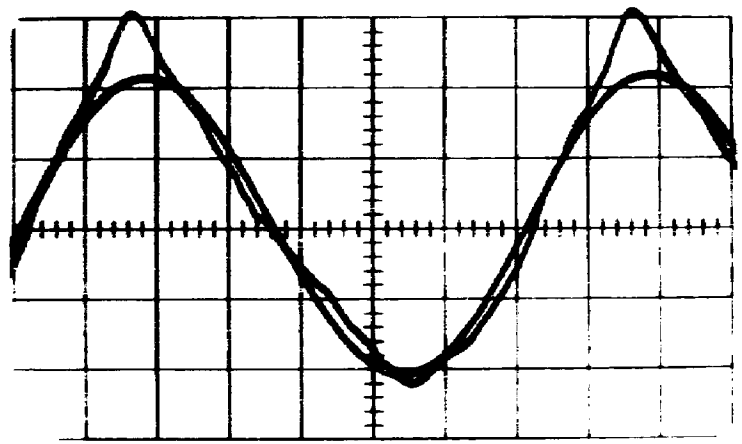
.172" DA



.368" DA

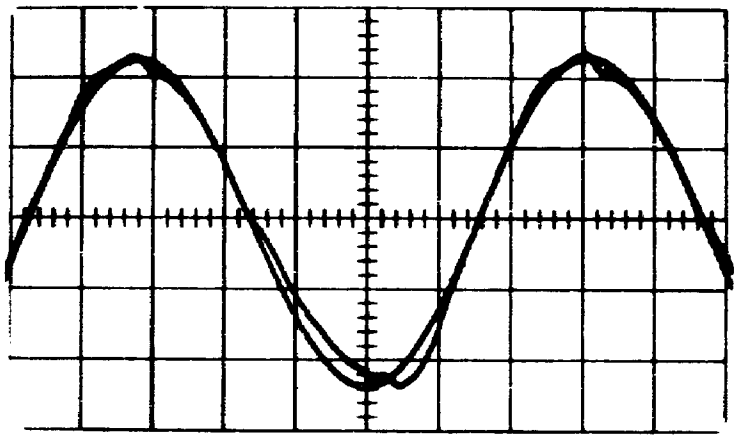


.627" DA

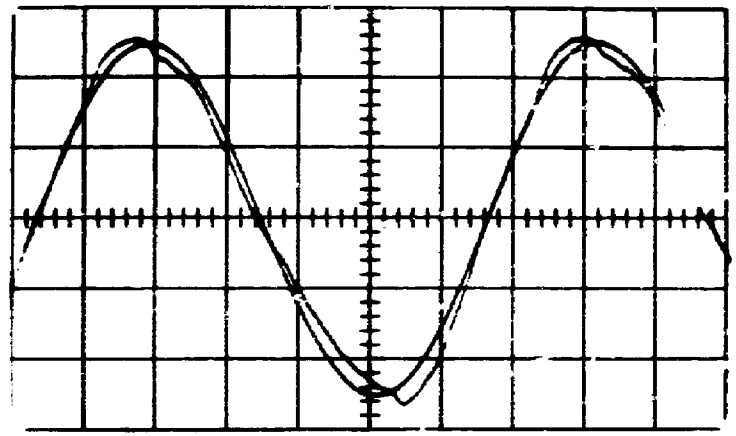


.94" DA

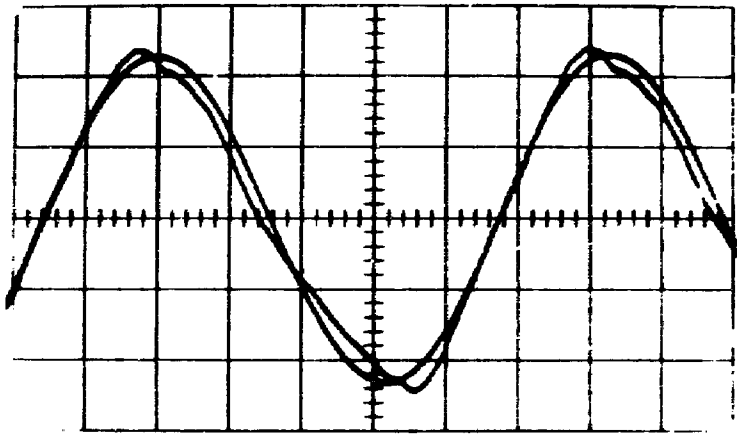
FIGURE 25 5 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS



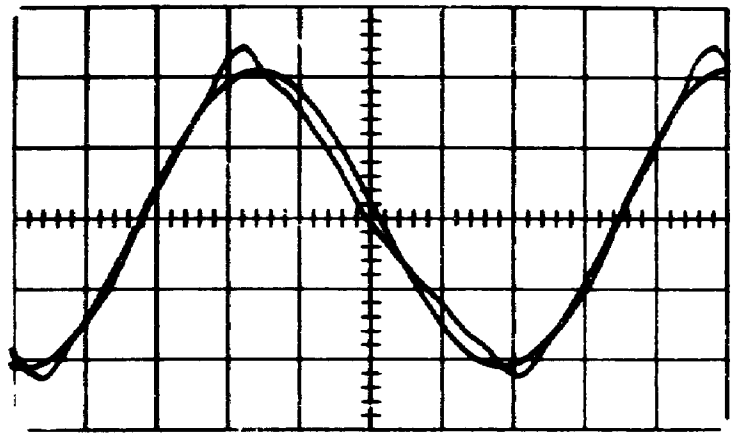
.148" DA



.212" DA

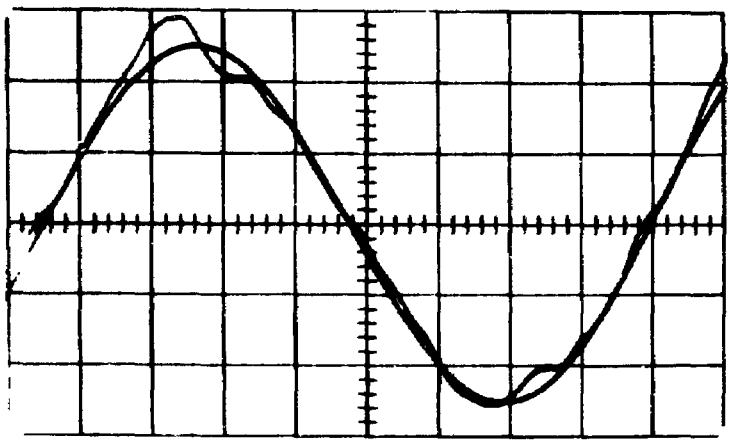


.294" DA

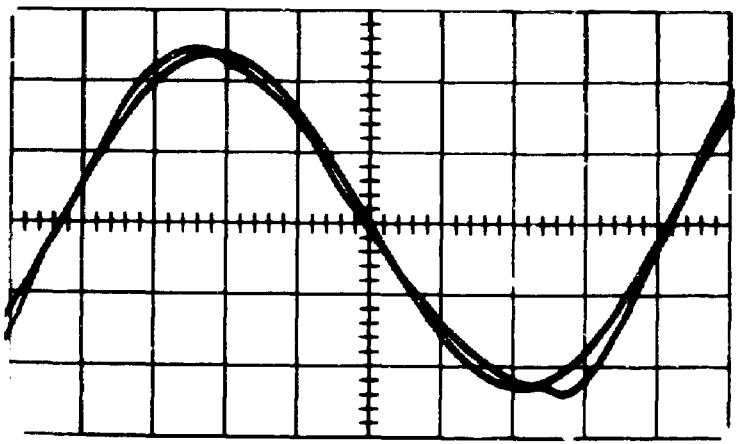


480" DA

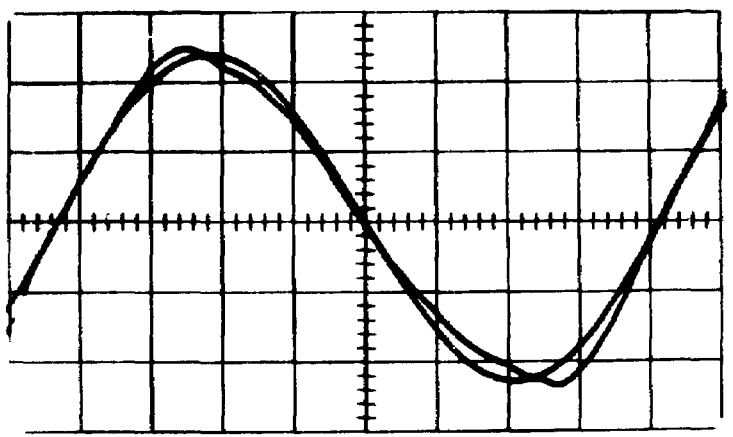
FIGURE 26 6 CPS ACCELERATION CURVE - SINE WAVE COMPARISONS



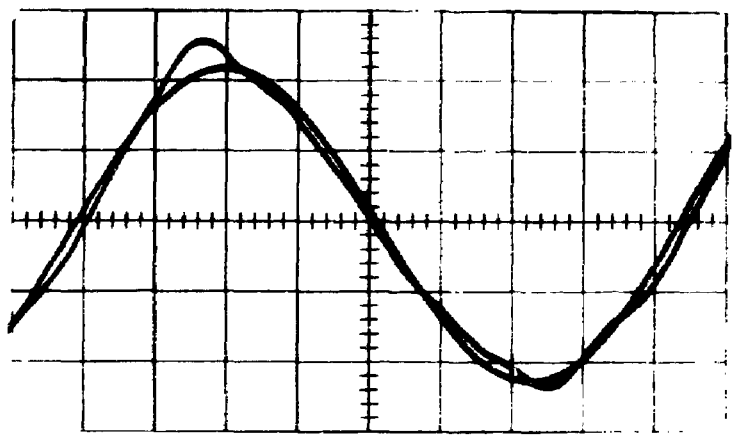
.04" DA



.113" DA

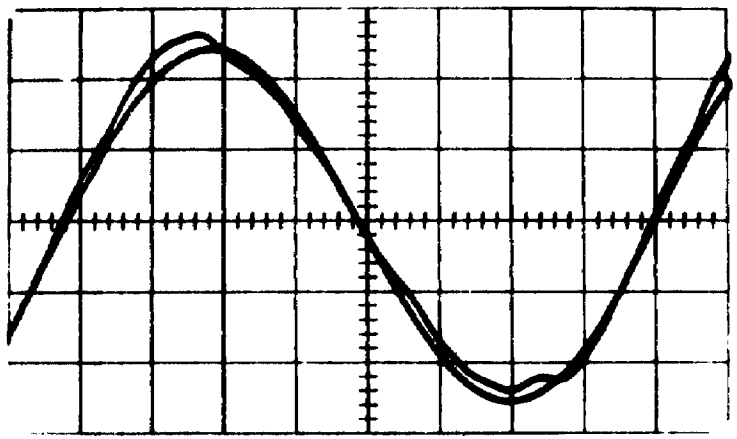


.183" DA

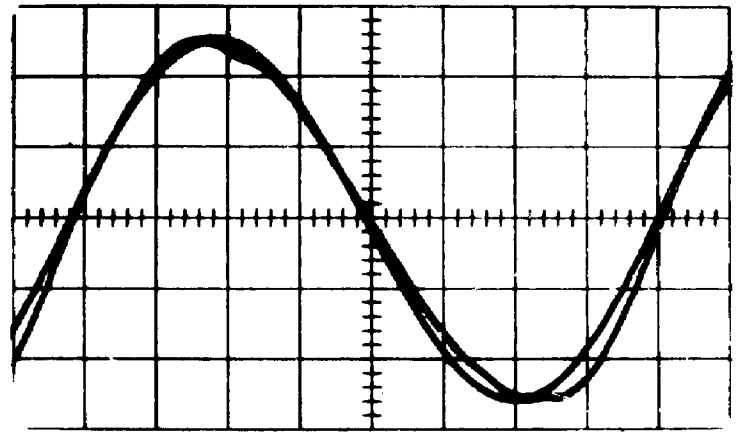


.310" DA

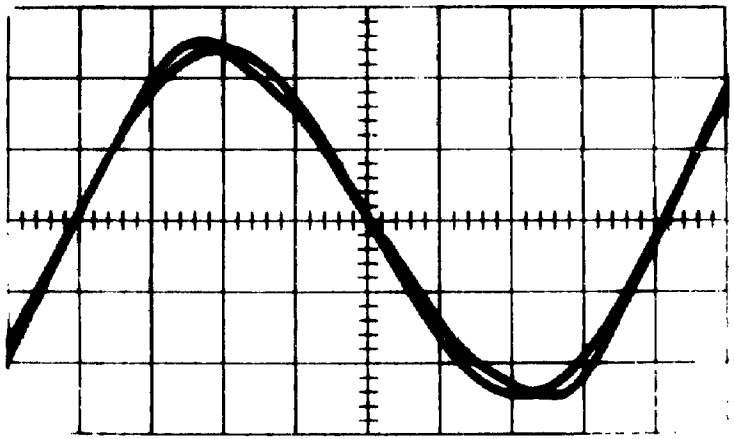
FIGURE 27 8 CPS ACCELERATION CURVE - SINE WAVE COMPARISONS



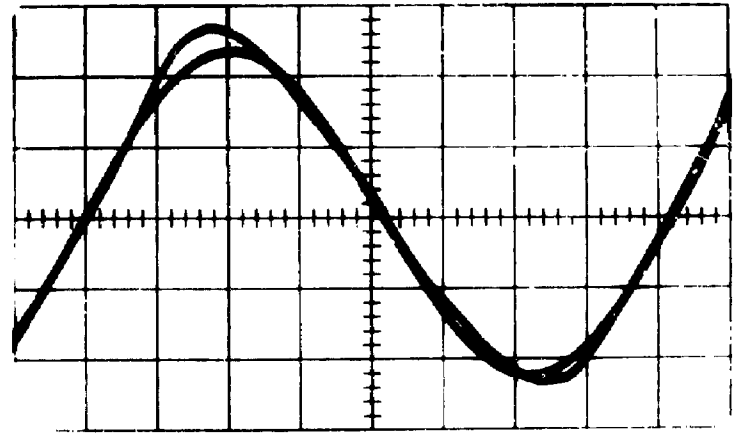
.055" DA



.103" DA

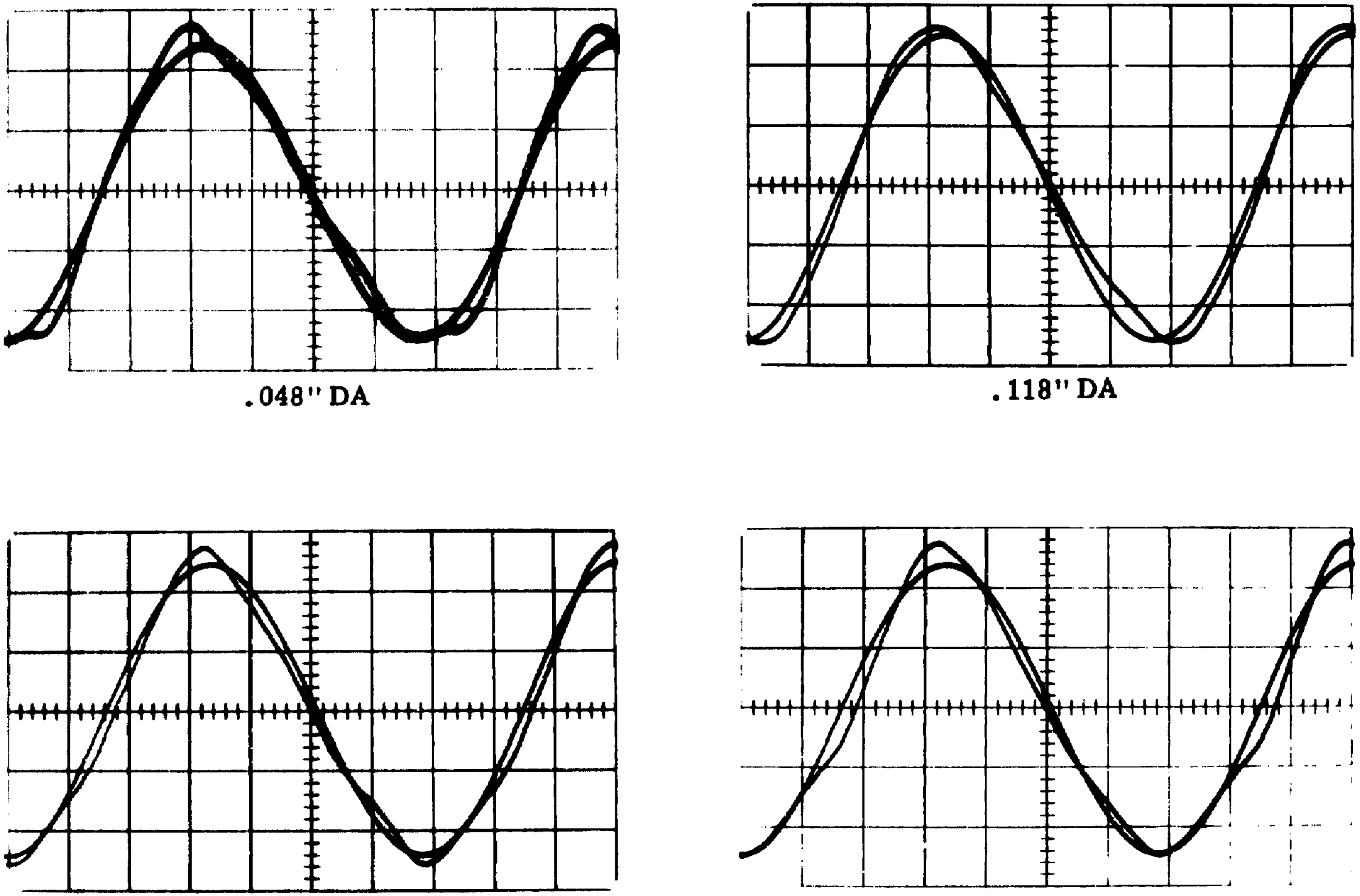


.145" DA



.20" DA

FIGURE 28 10 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS



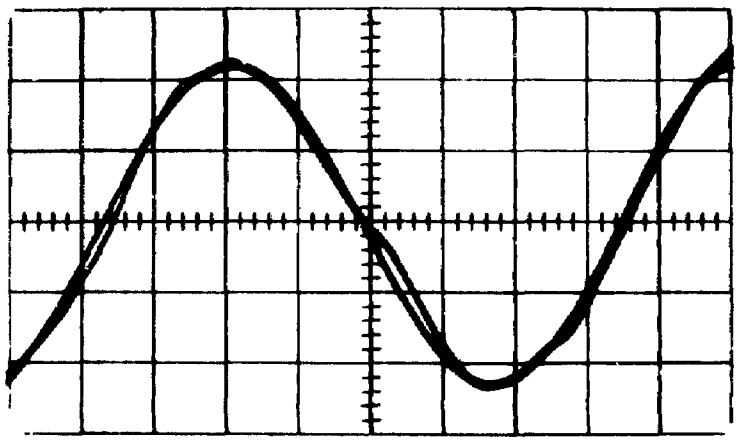
.048" DA

.118" DA

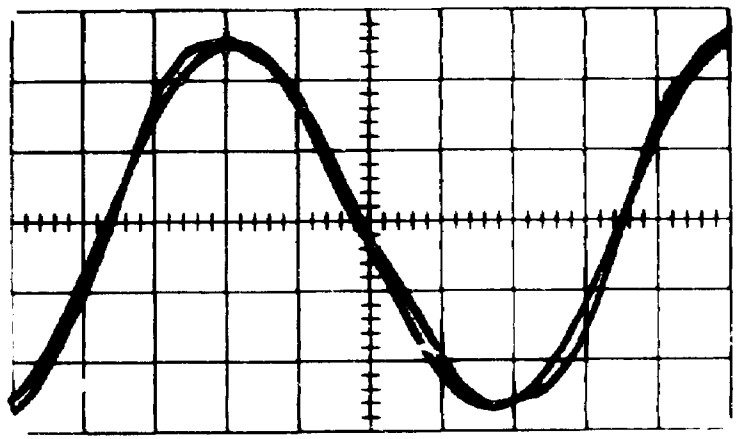
.155" DA

1.85" DA

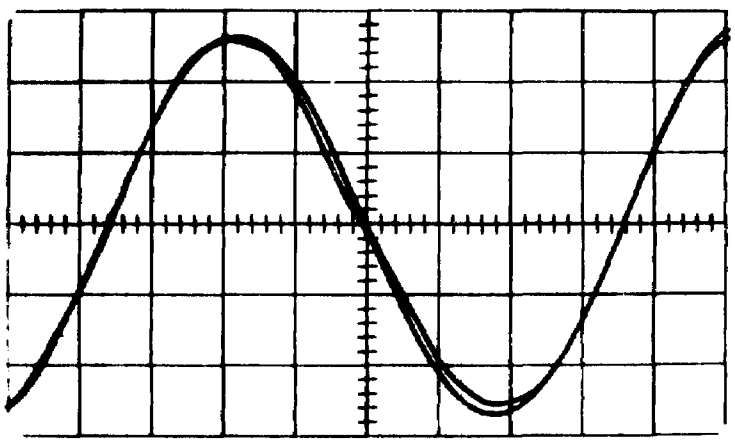
FIGURE 29 12 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS



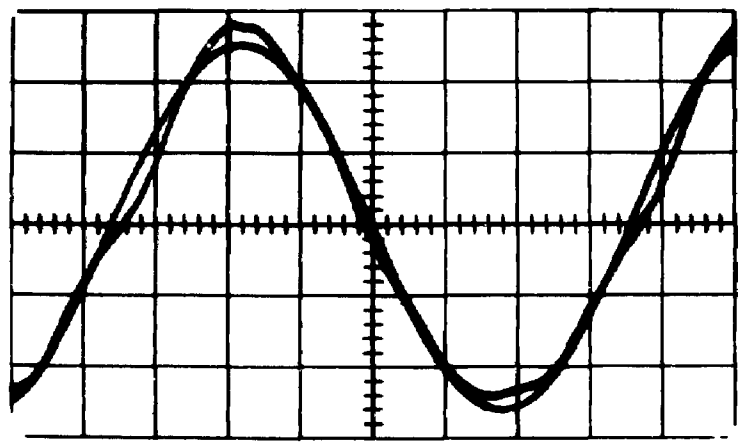
.025" DA



.079" DA

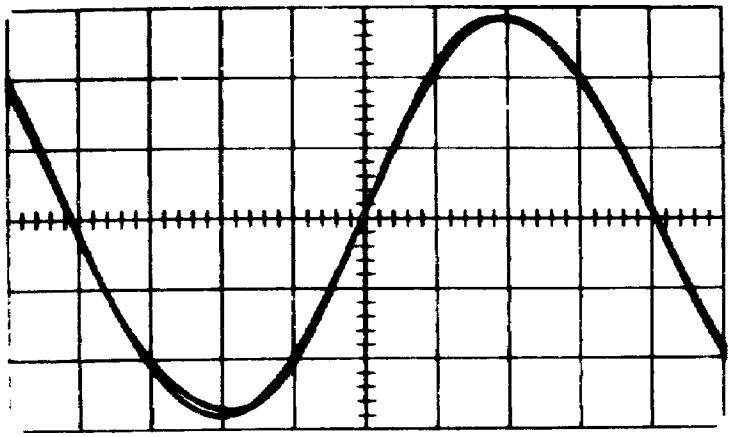


.110" DA

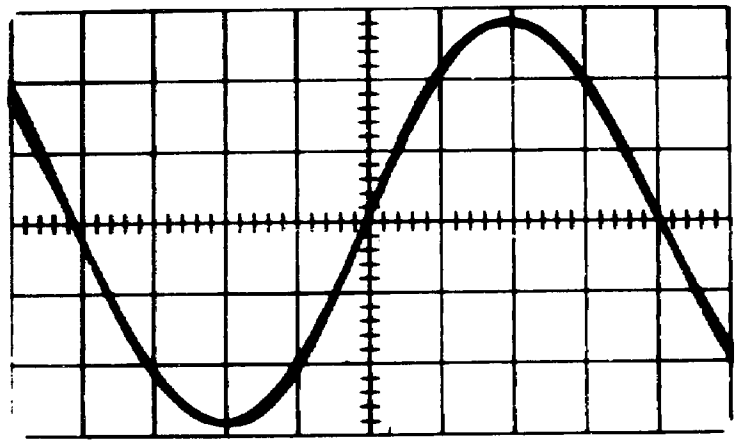


.192" DA

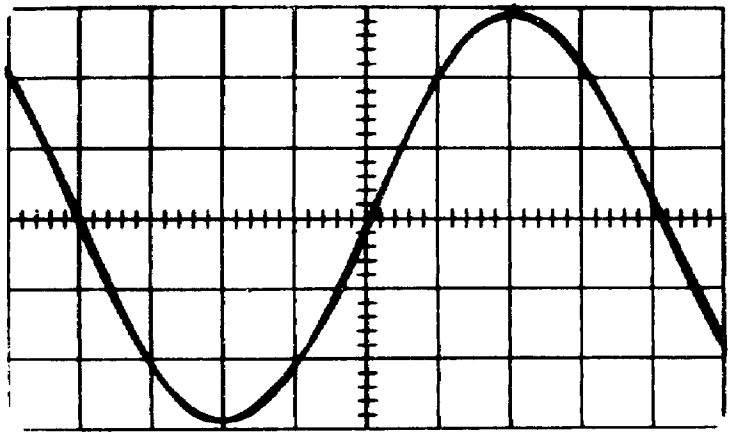
FIGURE 30 14 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS



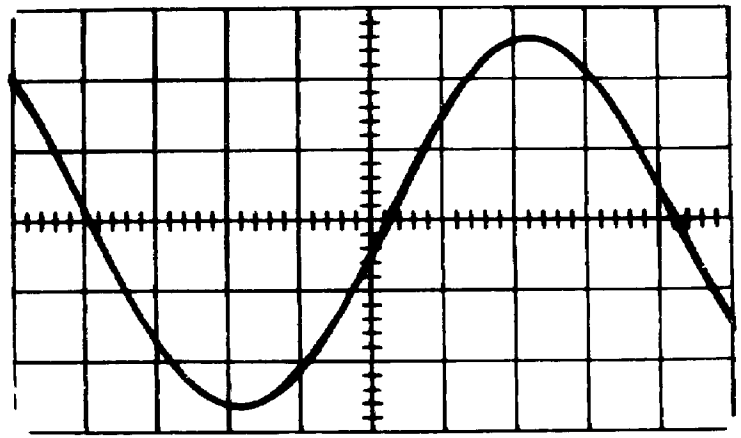
.039" DA



.068" DA

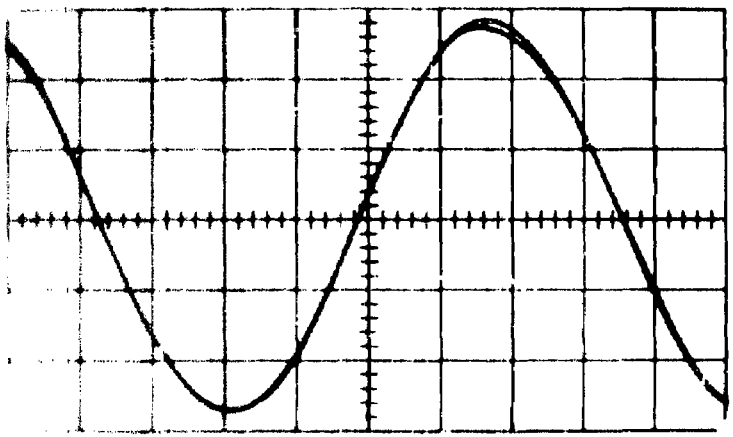


.096" DA

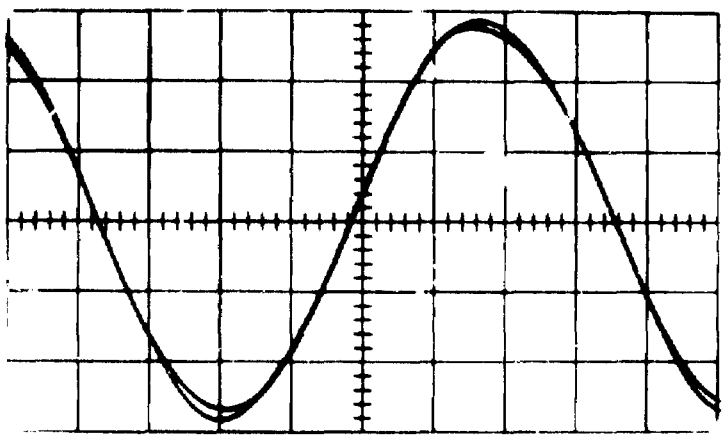


.17" DA

FIGURE 31 16 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS



.025" DA



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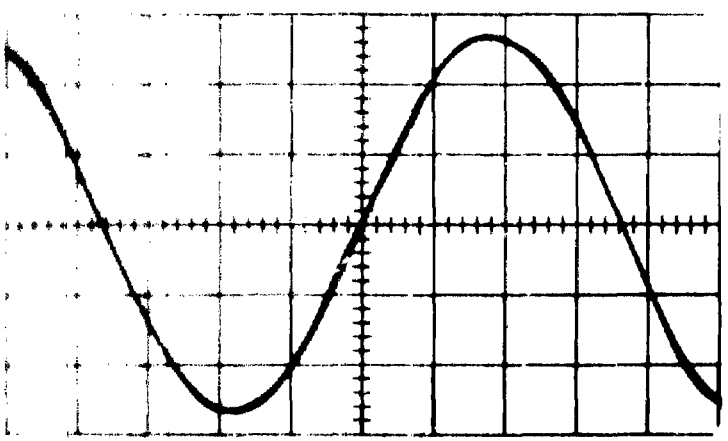
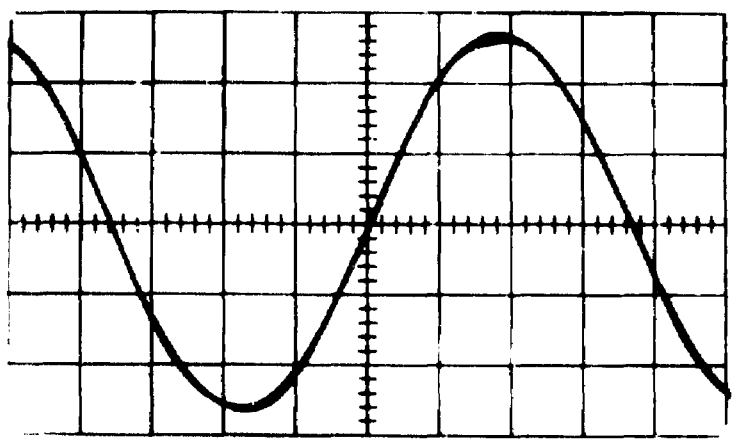
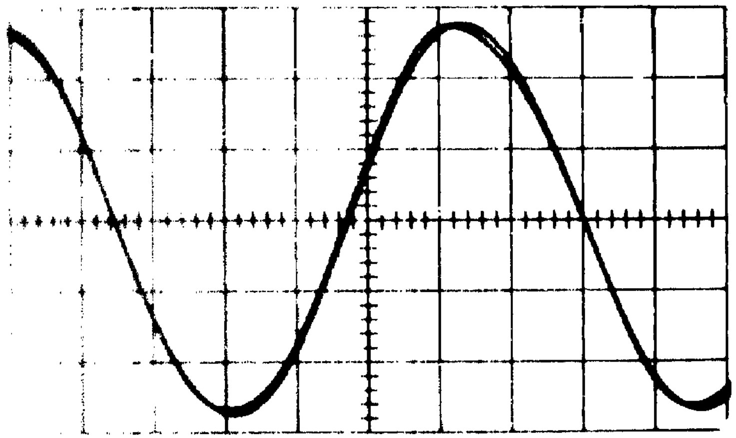


.12" DA

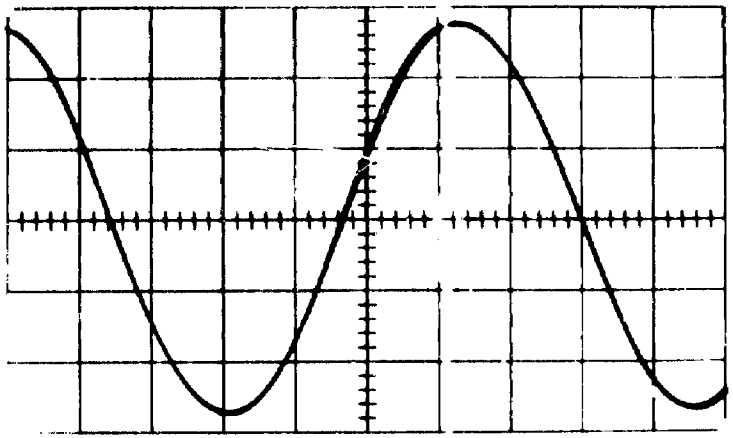


.152" DA

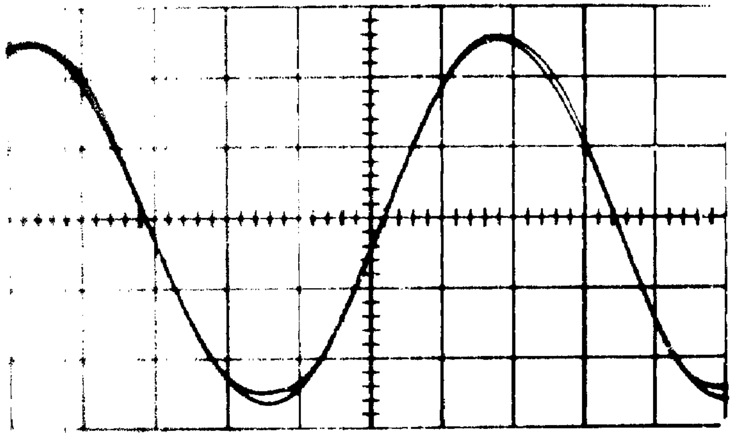
FIGURE 32 18 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS



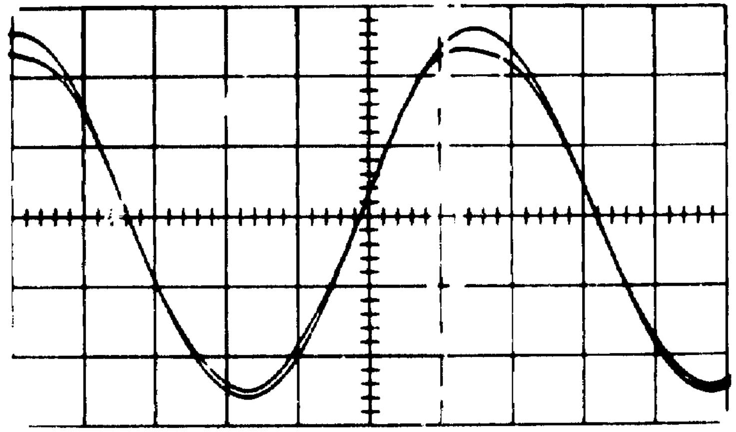
.012" DA



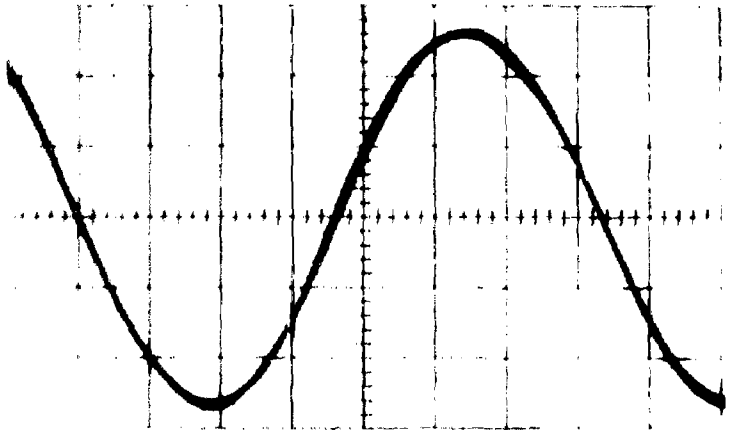
.035" DA



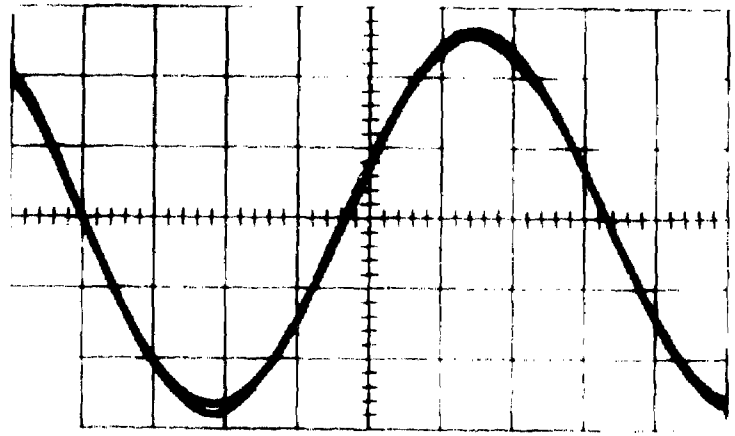
.104" DA



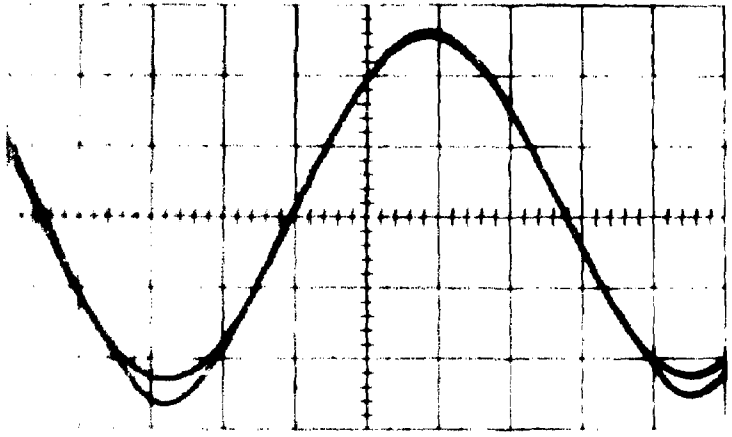
.134" DA



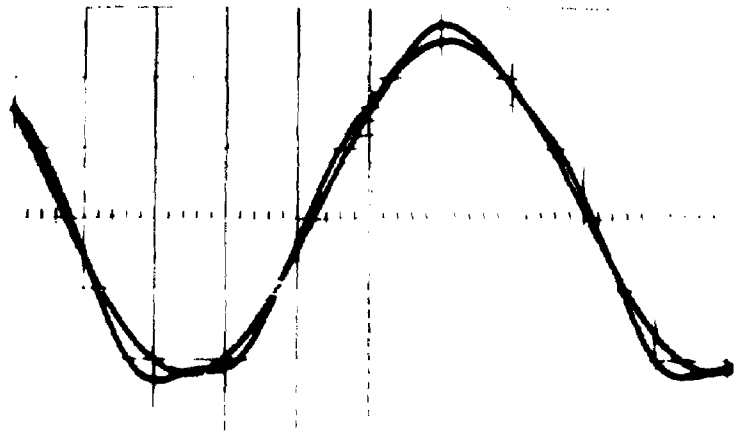
.019" DA



.027" DA

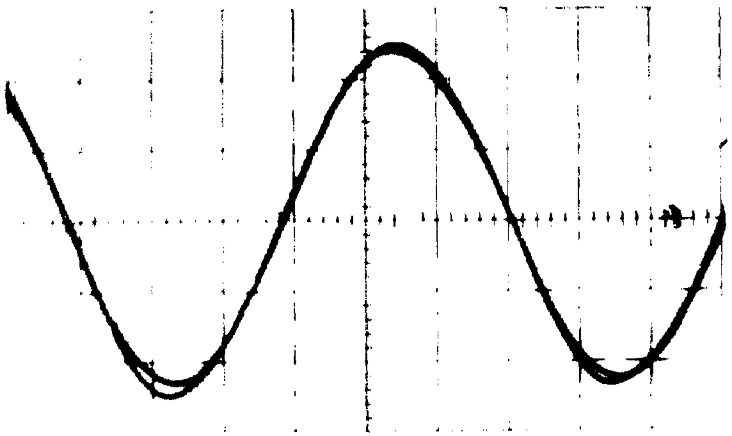


.034" DA

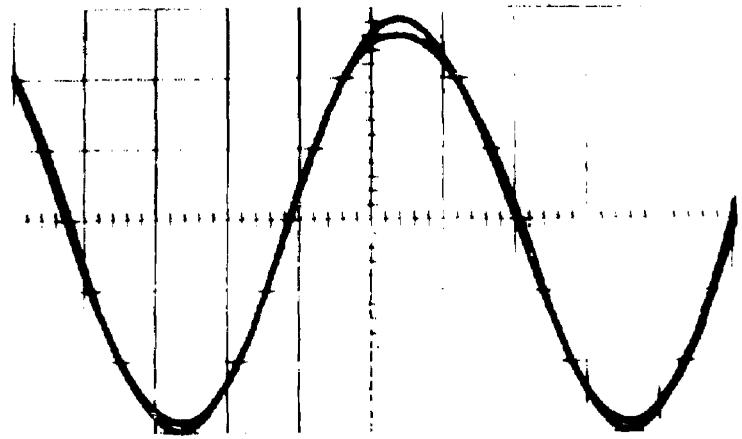


.112" DA

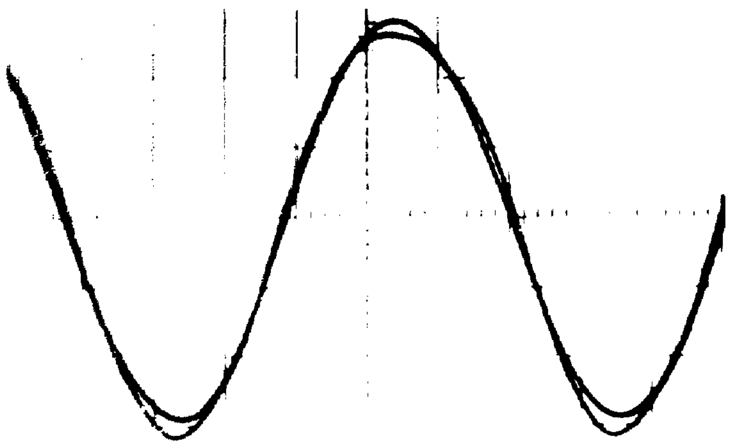
FIGURE 34 23 CPS ACCELERATION CURVE-SINE WAVE COMPARISONS



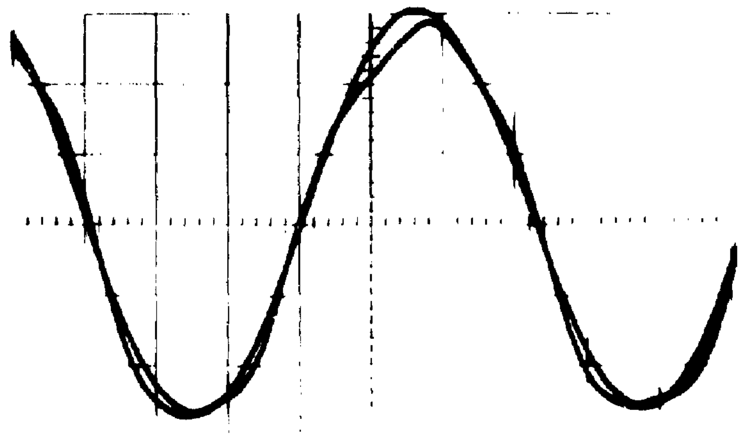
.012" DA



.024" DA



.026" DA



.082" DA

APPENDIX B

INSTRUCTIONS TO SUBJECTS

SUBJECT INSTRUCTIONS

In your participation as a subject in the vibration program, you will be aiding us in identifying some of the descriptive aspects of the sensation of vibration. These descriptions will prove valuable to the design engineer and those evaluating performance under vibratory environments. Vibration intensities which you will be asked to identify at various frequencies are defined on the accompanying sheet.

It should be noted that the labels provided are meant only to serve as indicators of the definitions to which you will fit the various vibration intensities. The description given may not fit your own personal interpretation of the labels. In this case, we are asking you, for the purpose of this test, to make sure you understand the given definition and work toward it disregarding the label.

You will notice that in each definition the word "you" appears, and with good reason. What we are looking for is your interpretation of the defined intensities, not what you think would be true for others. Also, for this reason we request that you not discuss among yourselves any of the levels or conditions of vibration. Individual reactions are required if we are to accomplish our objectives.

During the test sequences you will be presented, by means of a visual display, a label referencing the definition to which you are to adjust the vibration intensity. You will have control of the facility and will be able to increase, decrease, or maintain any vibration intensity within facility limits. In each test each identification will be made twice, but order of their appearance will vary from test to test. Also, since the vibration mechanism is limited for safety and equipment reasons, some frequencies may not contain for you the intensity required for one or more of the definitions. In these instances, where you request through your controls, a level beyond equipment capability, notification to that effect will be made by the experimenter and a new definition will be requested. You will then proceed with the new adjustment.

Control of the facility is accomplished by means of two pistol type hand grips held in either hand. Each has a two position "trigger" switch for the index finger and a thumb actuated push button located on top. The trigger switch controls upward and downward table movement respectively with the right and left hand. Hard

[illegible] vibration. The left one shuts down the facility and is provided for use only if you feel for any reason you must immediately stop vibration.

On the right hand side of the display panel is an arrow pointing up. This will be illuminated an amber color when you actuate the right hand switch to increase vibration intensity. When the switch is pressed down hard, to use the higher rate of change, the arrow illumination will be white. The down-pointing arrow on the left hand side of the panel provides the same indications for the left hand control while decreasing vibration intensity.

In making the vibration adjustments, we are interested in those judgements or feelings only with regard to vibration as a sensation and not with respect to your experiencing this as an environment in which to do something else. Thus, do not react to the vibration facility as a simulator and judge its characteristics as if you were performing some kind of task or operation. Consider the vibration only as a stimulus in its own right, keeping your attention centered on the lighted panel. Do not try to evaluate or compare levels by relating your movement to any fixed object in the area. We want your unbiased opinion as to the effect you feel from the vibration. If it helps your concentration to close your eyes, this is permissible. If, at any time, you cannot find the desired vibration sensation, please notify the experimenter and he will proceed with the next step.

Daily Subject Instructions

[illegible] vibration in our experimental techniques and therefore a minimum of differences in your results, several items of [illegible] be reviewed prior to each test session. We realize you have heard and remember most if not all of these items from previous tests, but we ask your indulgence in the review.

Most important, of course, is an understanding of the four levels of vibration which you identify at each frequency and we have booklets to review these at the start of each test period.

Definition of Subjective Vibration Levels

1. Perceptible — This is the lowest intensity of vibration which can be felt. Working up the scale, this is the point at which you first become aware that you are receiving vibration. Going down the scale, this is the point at which all sense of vibration disappears.

2. Mildly annoying — This is the lowest intensity of vibration at which any unpleasant or annoying effects are felt. Below this point you are aware of the vibration, but it arouses no undesirable feelings. Below this point there may even be some pleasant aspects.

3. Extremely annoying — This is the lowest intensity of vibration at which unpleasant or annoying effects become disturbing to a major degree and cannot be ignored. You would prefer not to continue at this intensity without good reason.

4. Alarming — This is the intersity of vibration at which you begin to experience concern for your physical well-being. There is not necessarily any pain present, but there is a distinct desire to reduce the vibration severity. You have misgivings about staying at this level any longer or going beyond it.

Also, we ask that you sit erect in the chair and not try to reduce the vibration inputs through tensing of the legs, lifting off the chair, etc. You may, of course, reduce the effects of vibration received through techniques of your own choosing, but we ask that you don't attempt to modify what is received.

Too, we have found in previous tests that using the fast rates of vibration change (hard depression of the appropriate switch), has worked most satisfactorily when going between levels. How you choose to approach and decide upon the exact level of vibration which matches the definition provided is your choice, but we ask that you use the fast rates between levels where large changes are required. This is most important in reducing vibration after making selections at the higher levels.

[illegible] the necessary data.

As for communications, none are required on your part. We will notify you when the table is coming up prior to each vibration and when the test is started and over. No others are scheduled. However, your microphone is "hot" and you may make comments concerning the vibration or ask questions at any point during the test. Also, we have limits set on the table at each frequency and it is possible that you may reach these limits without identifying 1 or more of the defined levels. In such cases, we will notify you of "maximum amplitude" and provide you with a new level. It is also possible that you can not find a vibration in some case which you feel matches the definition provided. In this event if you will notify us of the fact we will again proceed to the next level.

Are there any questions?

APPENDIX C

INDIVIDUAL SUBJECT RESPONSE CURVES

FIGURE 36B
SUBJECT #1 SECOND SERIES OF TESTS

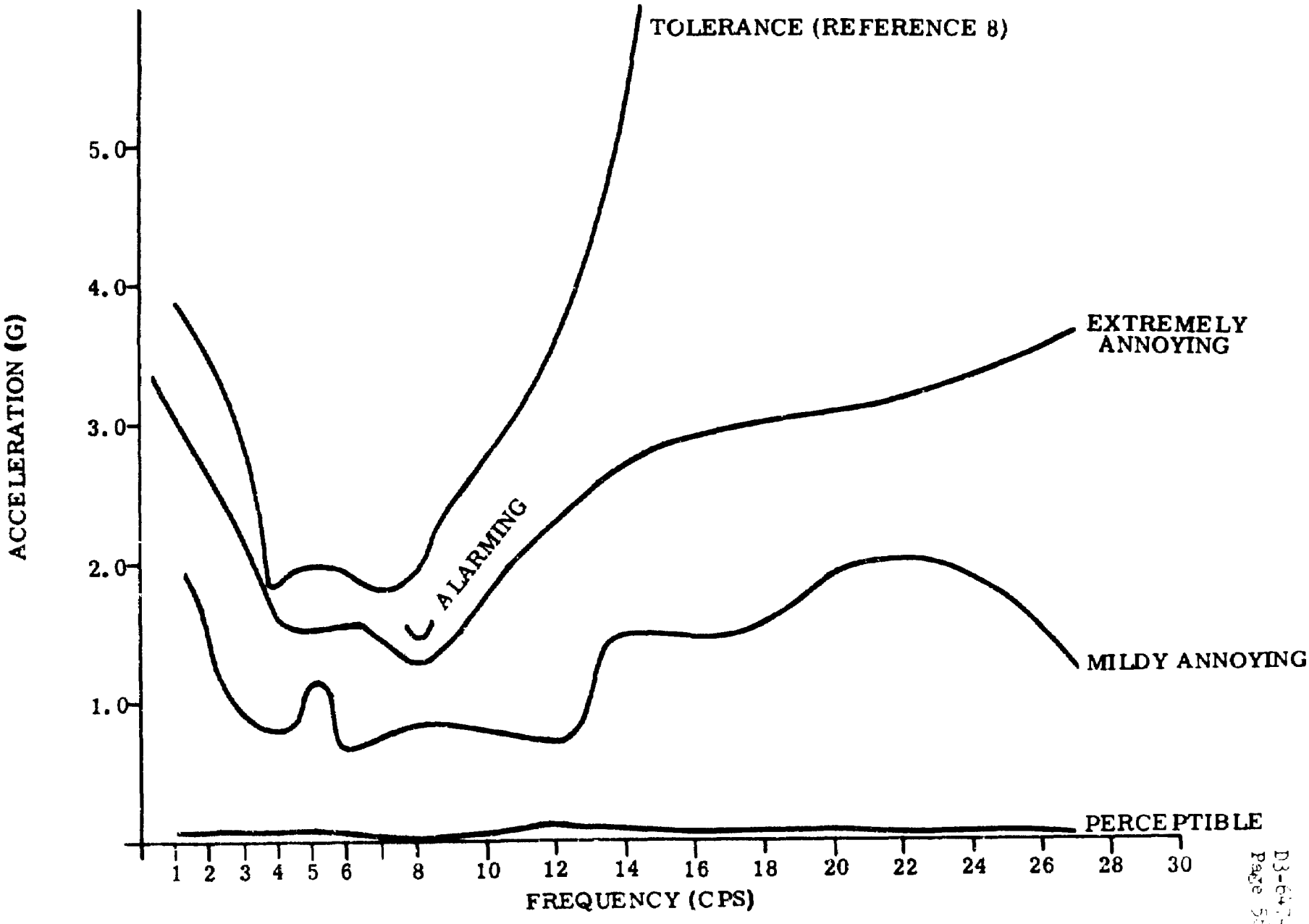


FIGURE 36A

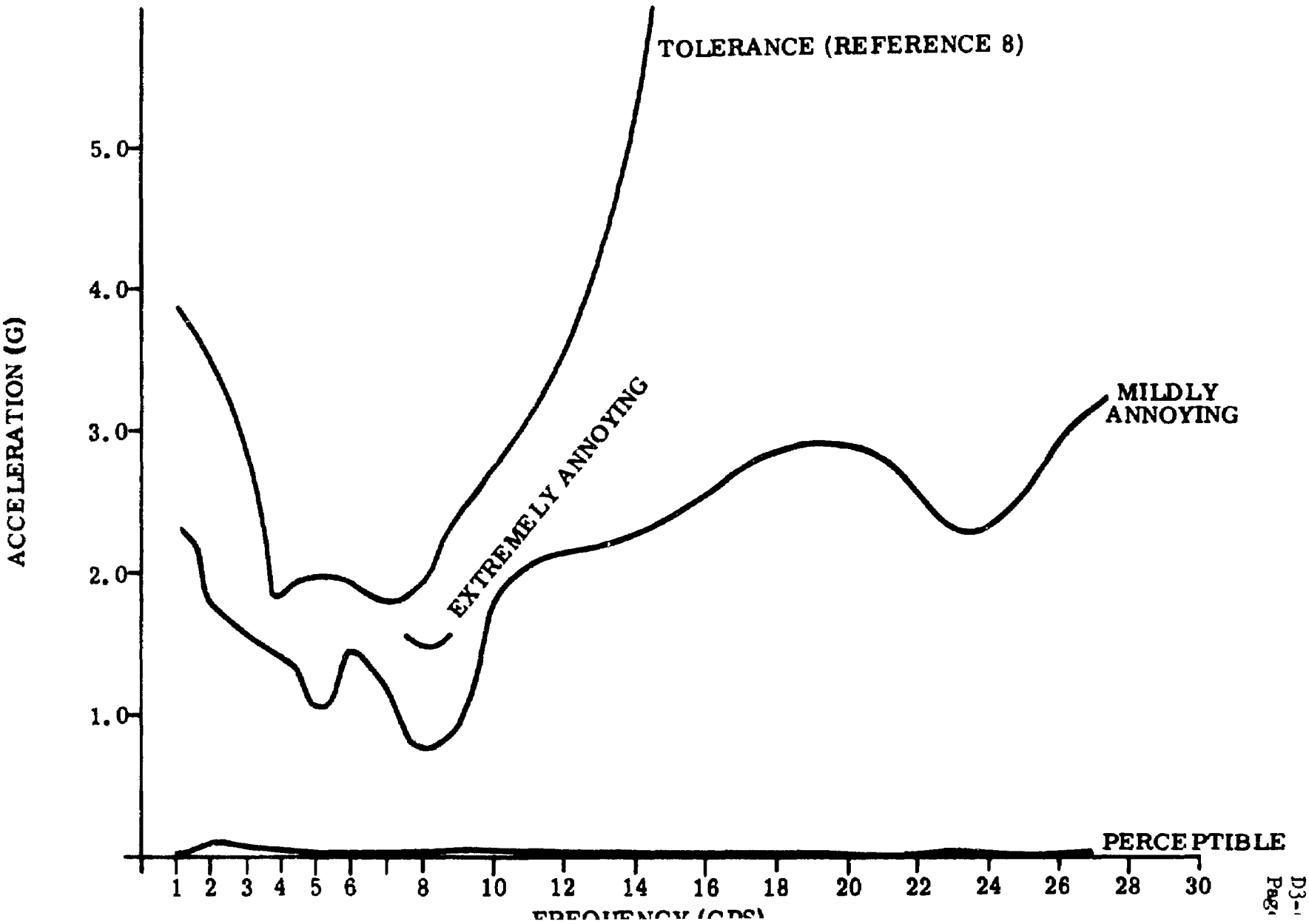

TOLERANCE (REFERENCE 8)
EXTREMELY ANNOYING
MILDLY ANNOYING
PERCEPTIBLE
ACCELERATION (G)
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 8 10 12 14 16 18 20 22 24 26 28 30

FIGURE 37B
SUBJECT #2 SECOND SERIES OF TESTS

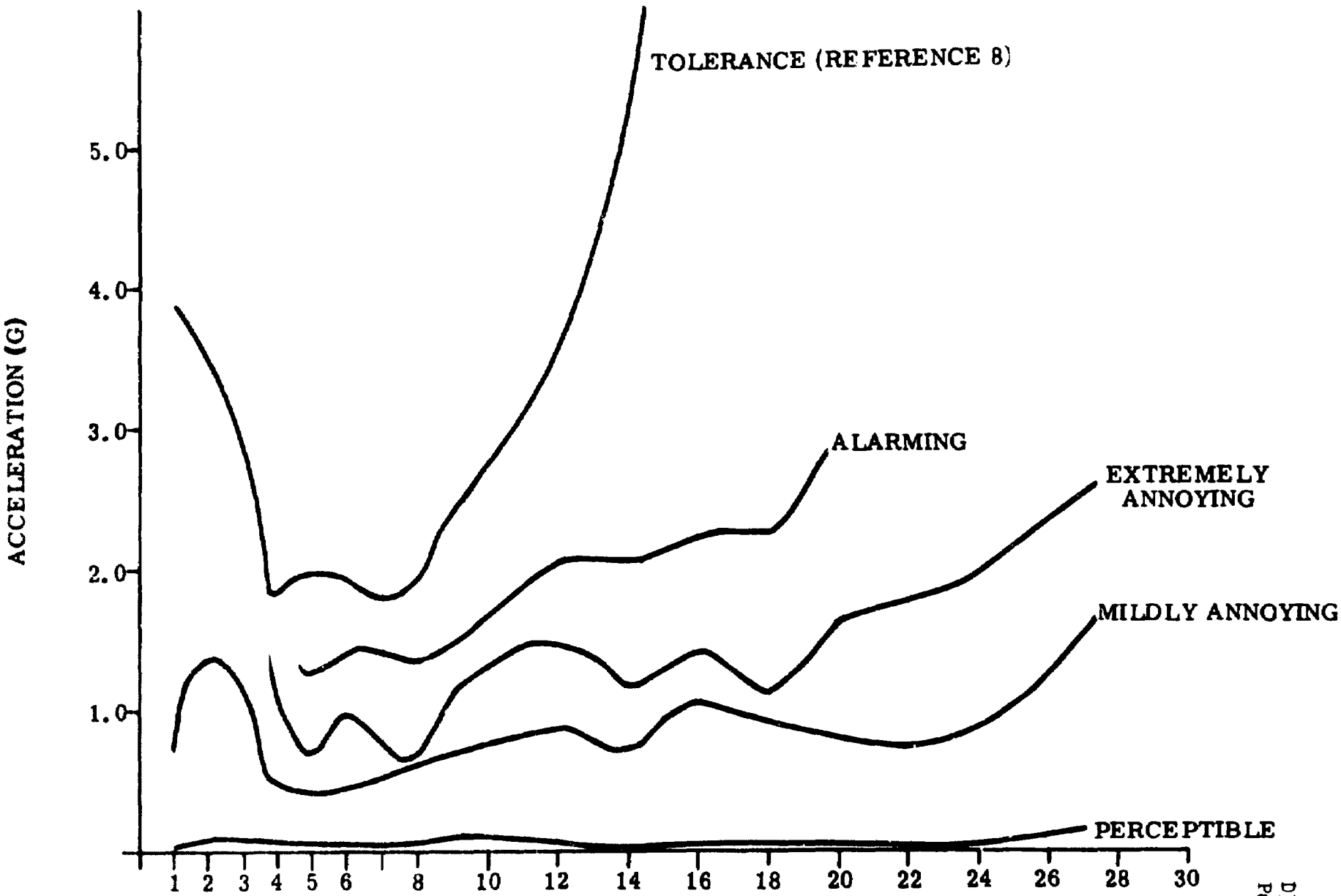


FIGURE 37A
SUBJECT #2 FIRST SERIES OF TESTS

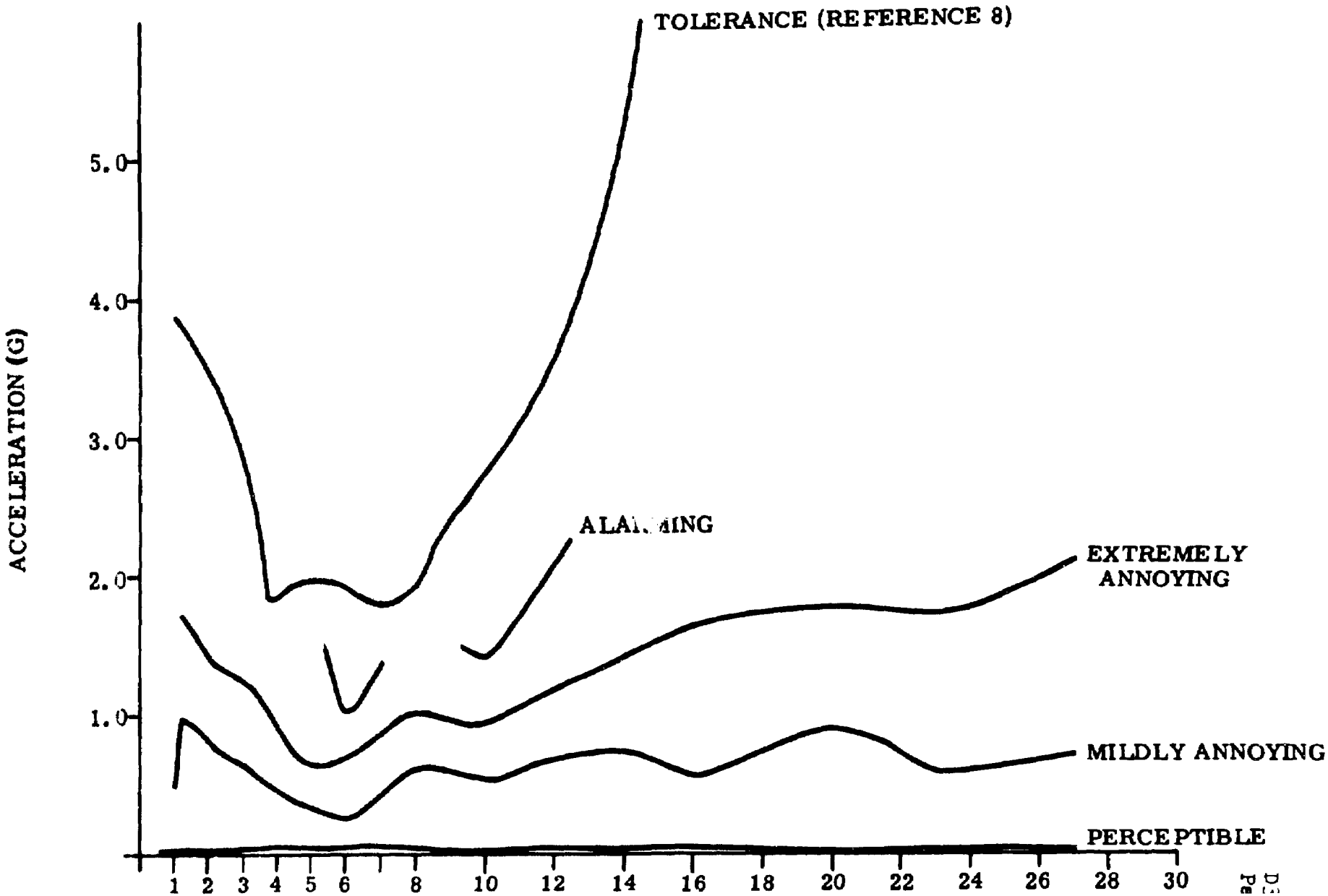

TOLERANCE (REFERENCE 8)
ACCELERATION (G)
5.0
4.0
3.0
2.0
1.0
ALARMING
EXTREMELY ANNOYING
MILDLY ANNOYING
PERCEPTIBLE
1 2 3 4 5 6 8 10 12 14 16 18 20 22 24 26 28 30

FIGURE 38B
SUBJECT #3 SECOND SERIES OF TESTS

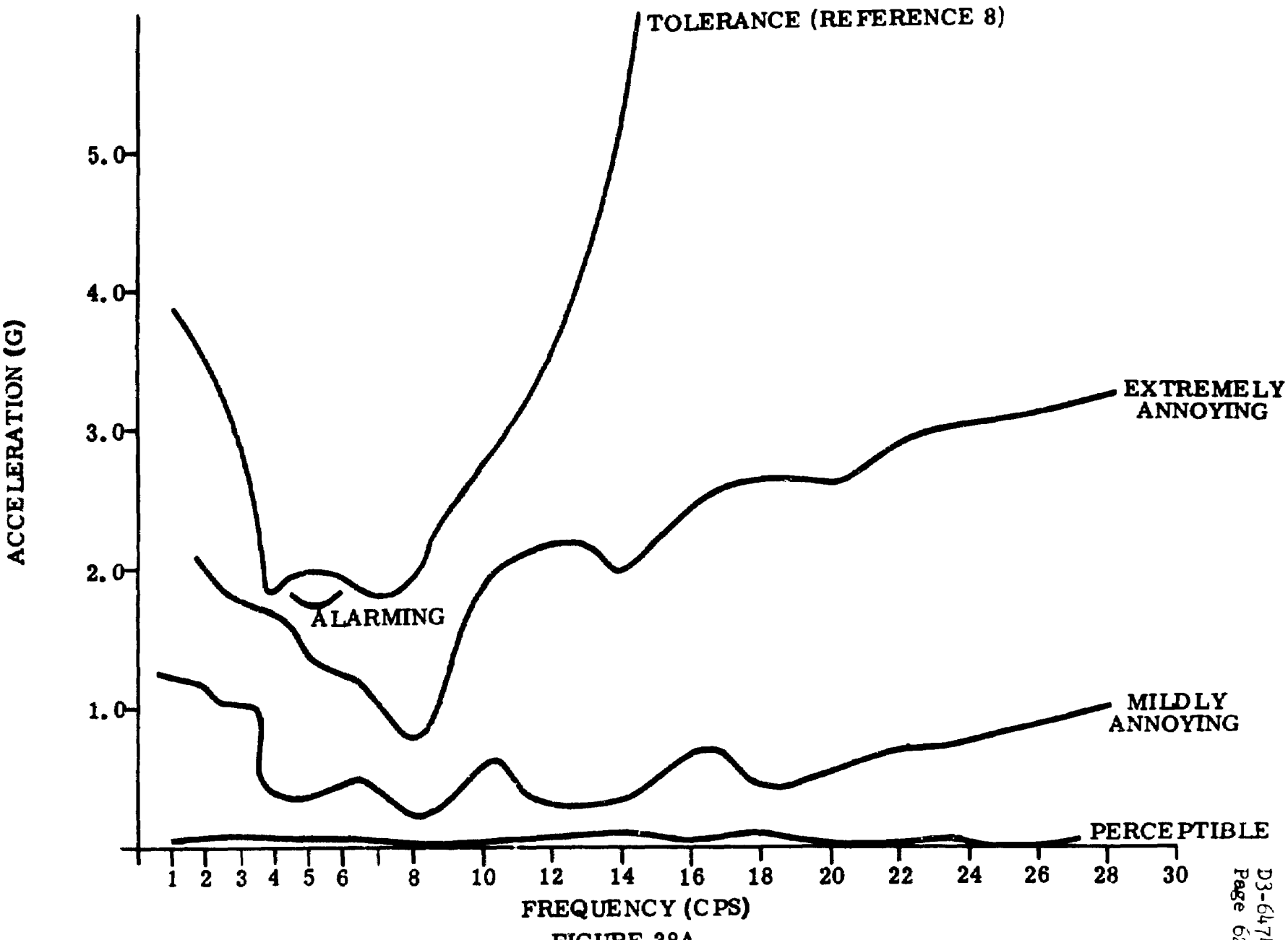


FIGURE 38A

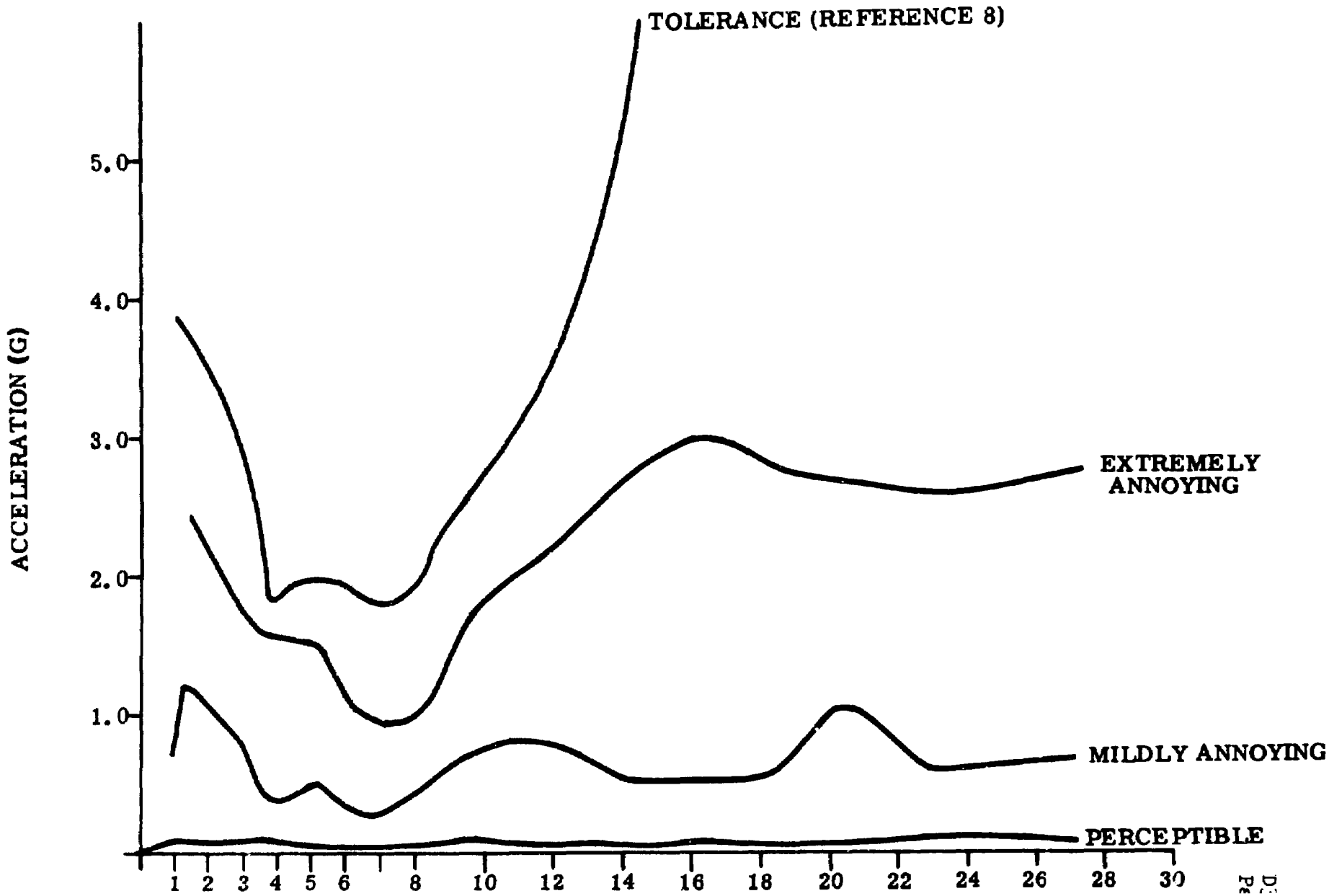

TOLERANCE (REFERENCE 8)
EXTREMELY ANNOYING
MILDLY ANNOYING
PERCEPTIBLE
ACCELERATION (G)
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 8 10 12 14 16 18 20 22 24 26 28 30

FIGURE 39B
SUBJECT #4 SECOND SERIES OF TESTS

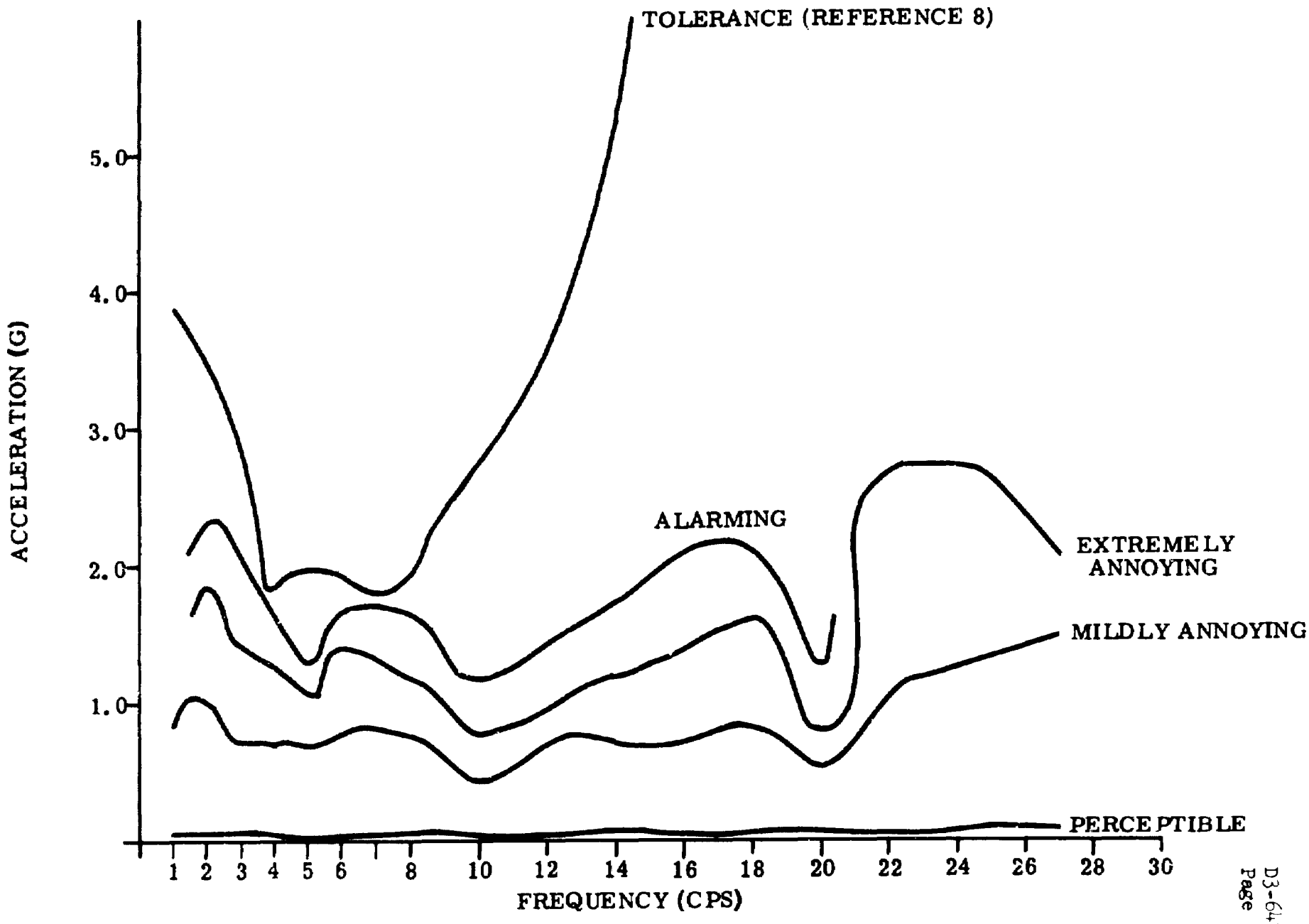


FIGURE 39A
SUBJECT #4 FIRST SERIES OF TESTS

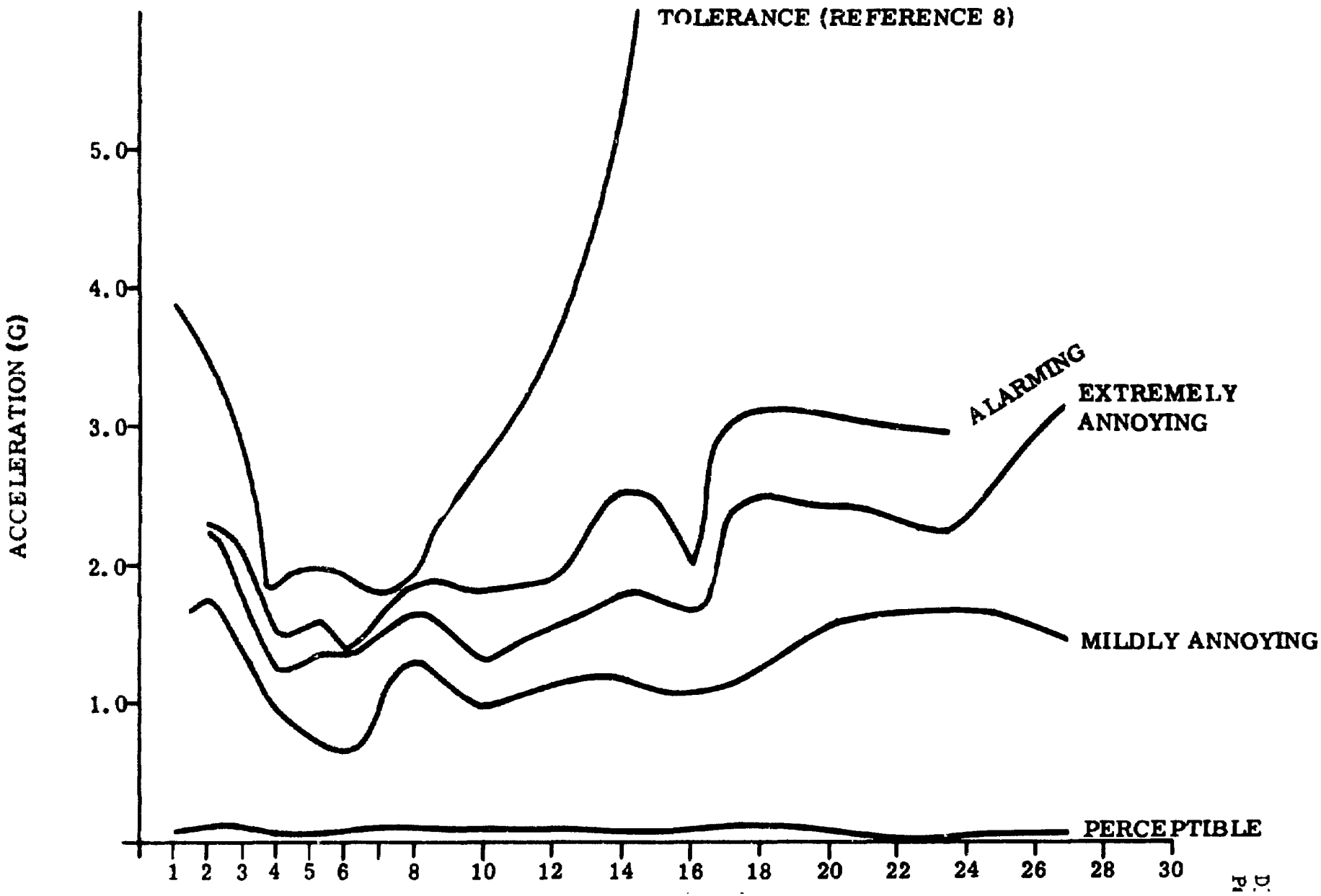

TOLERANCE (REFERENCE 8)
ALARMING
EXTREMELY ANNOYING
MILDLY ANNOYING
PERCEPTIBLE
ACCELERATION (G)
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 8 10 12 14 16 18 20 22 24 26 28 30

FIGURE 40B
SUBJECT #5 SECOND SERIES OF TESTS

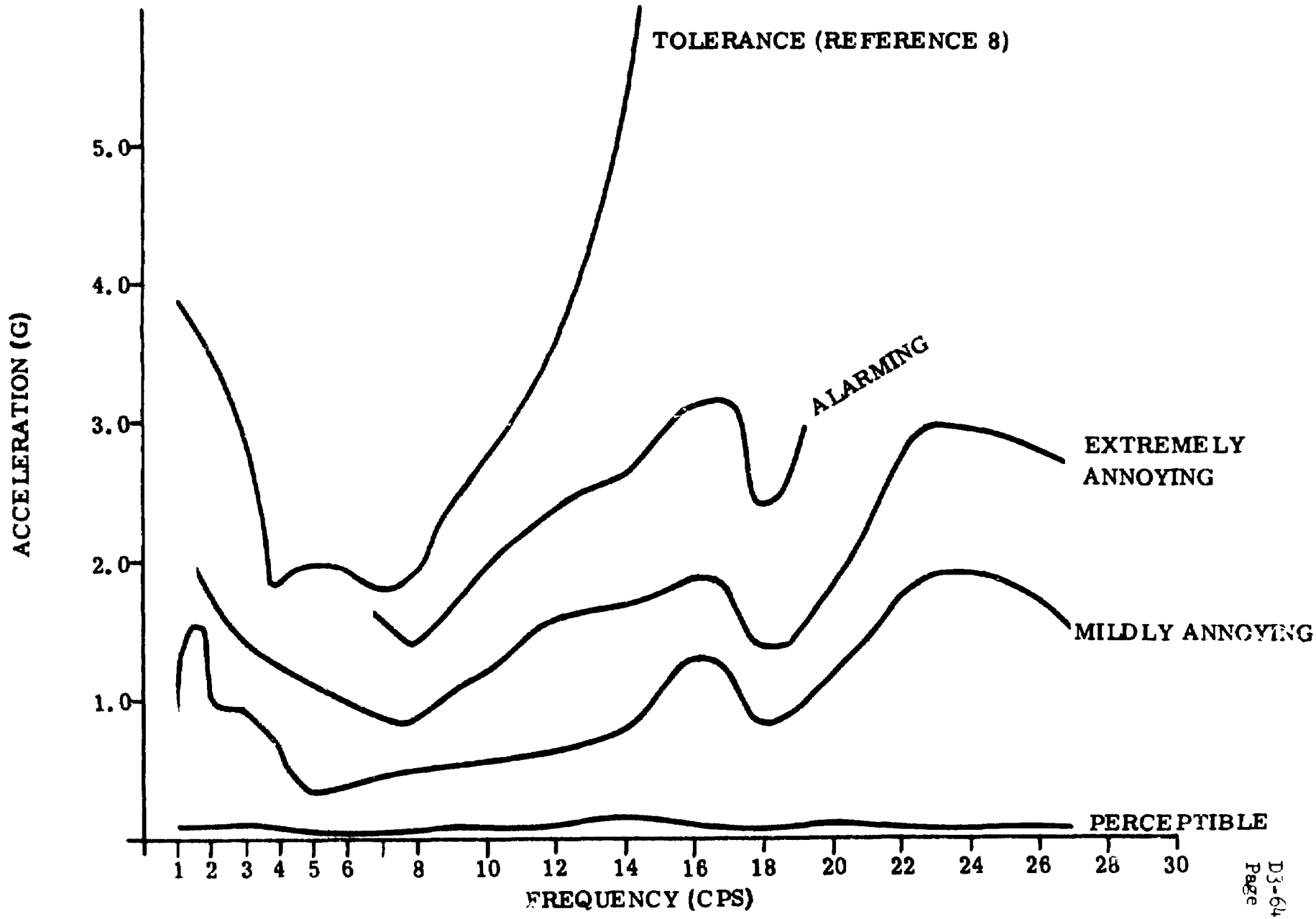


FIGURE 40A
SUBJECT #5 FIRST SERIES OF TESTS

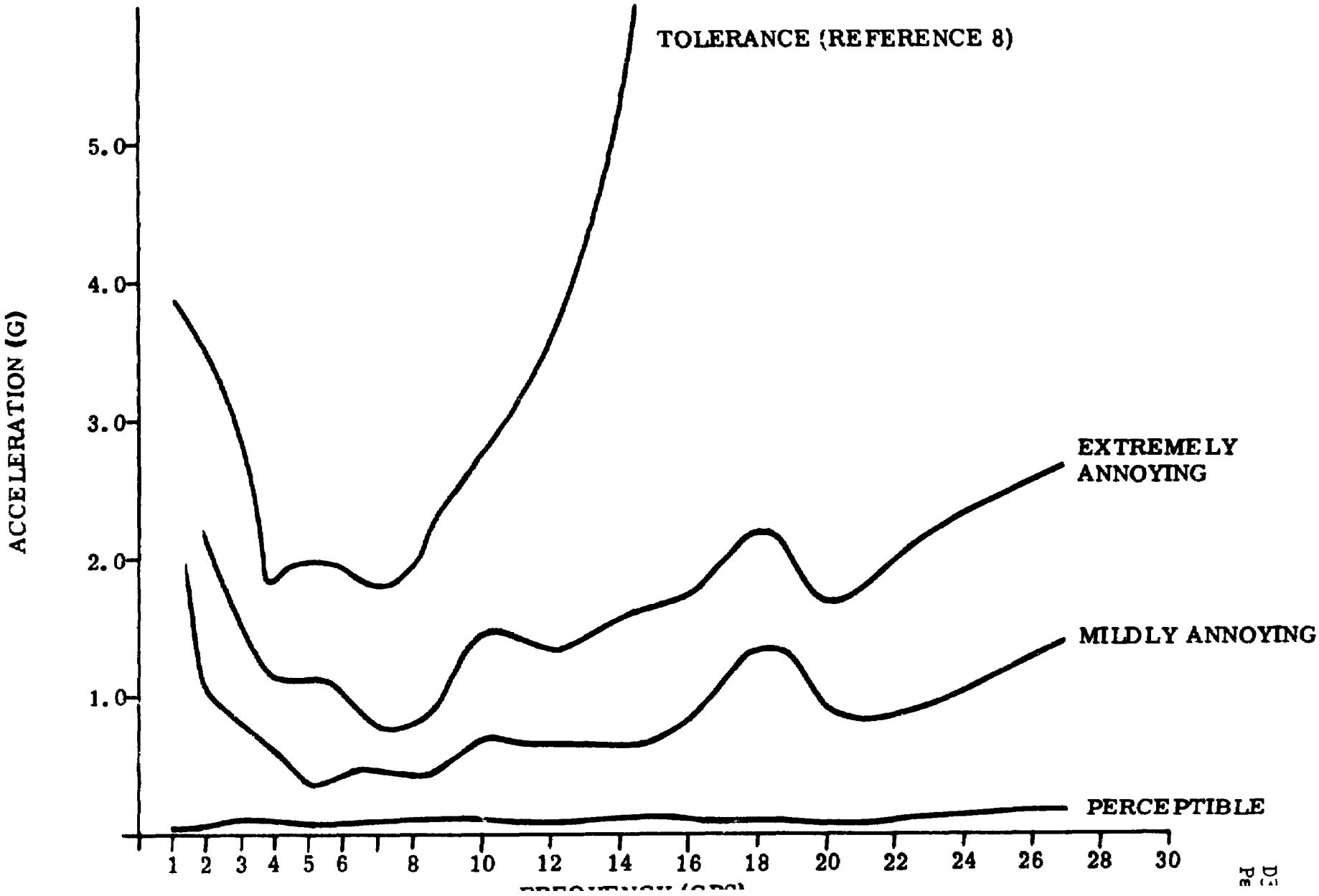

TOLERANCE (REFERENCE 8)
EXTREMELY ANNOYING
MILDLY ANNOYING
PERCEPTIBLE
ACCELERATION (G)
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 8 10 12 14 16 18 20 22 24 26 28 30

FIGURE 41B
SUBJECT #6 SECOND SERIES OF TESTS

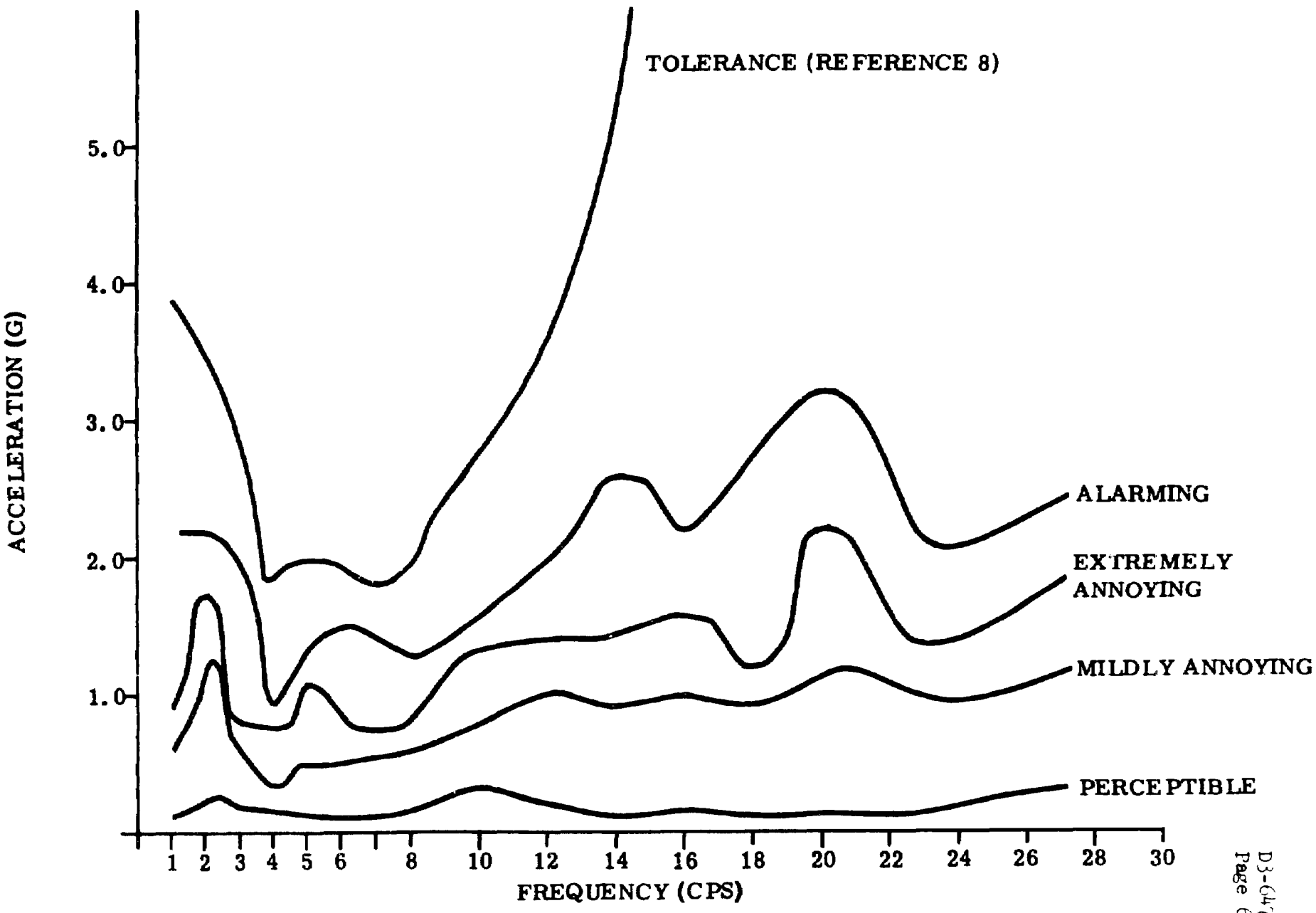


FIGURE 41A
SUBJECT #6 FIRST SERIES OF TESTS

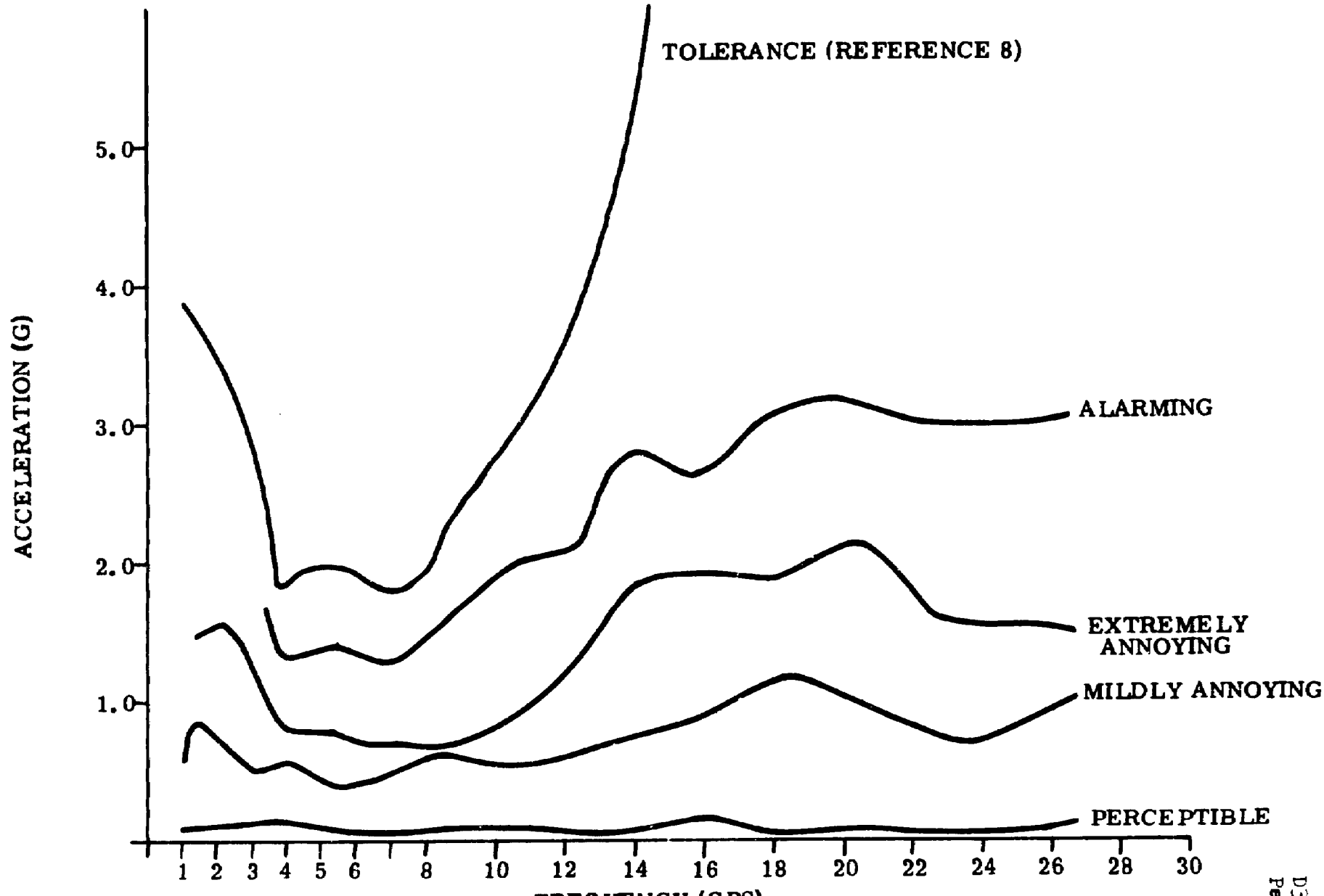

TOLERANCE (REFERENCE 8)
ALARMING
EXTREMELY ANNOYING
MILDLY ANNOYING
PERCEPTIBLE
ACCELERATION (G)
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 8 10 12 14 16 18 20 22 24 26 28 30

FIGURE 42B
SUBJECT #7 SECOND SERIES OF TESTS

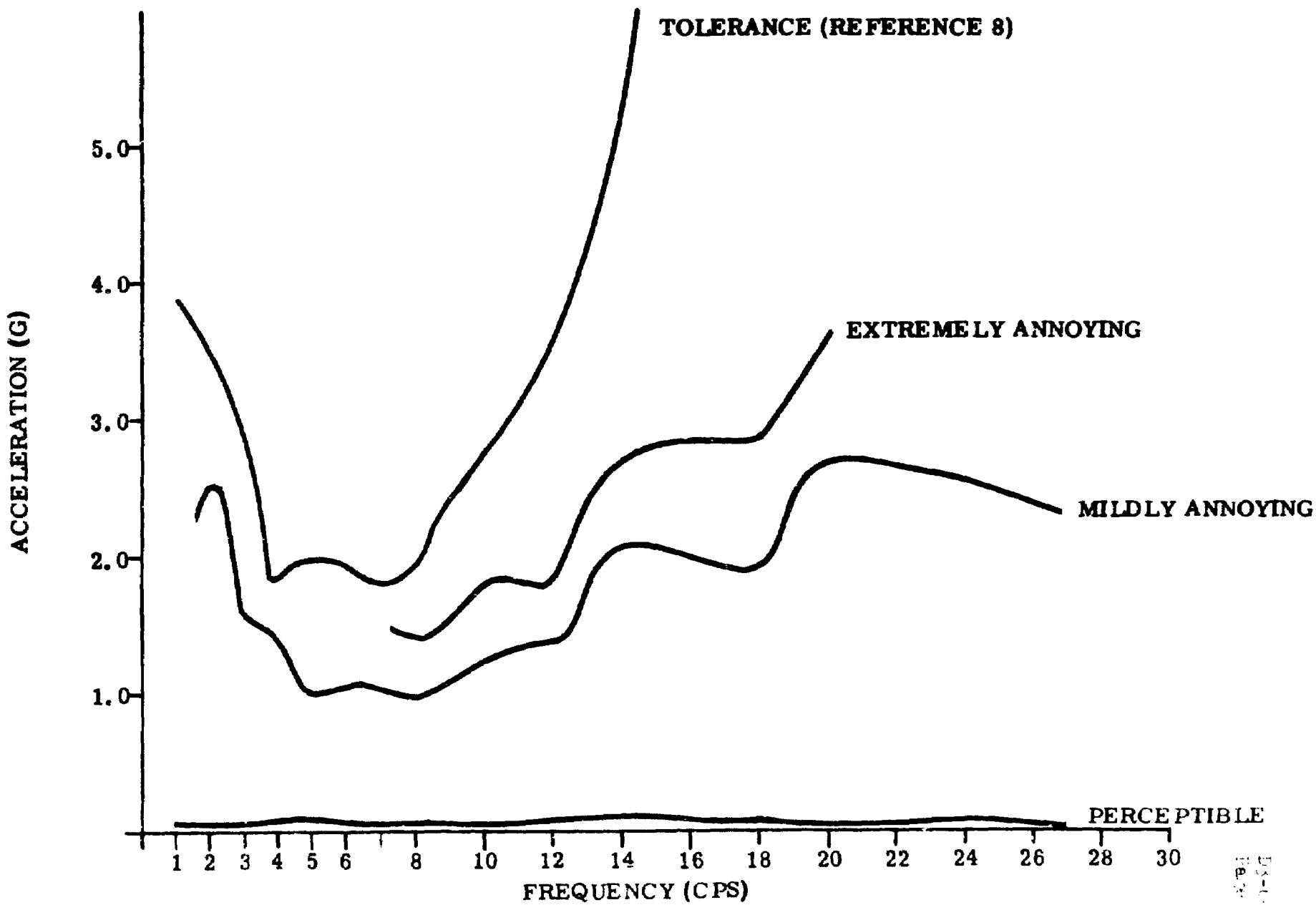


FIGURE 42A
SUBJECT #7 FIRST SERIES OF TESTS

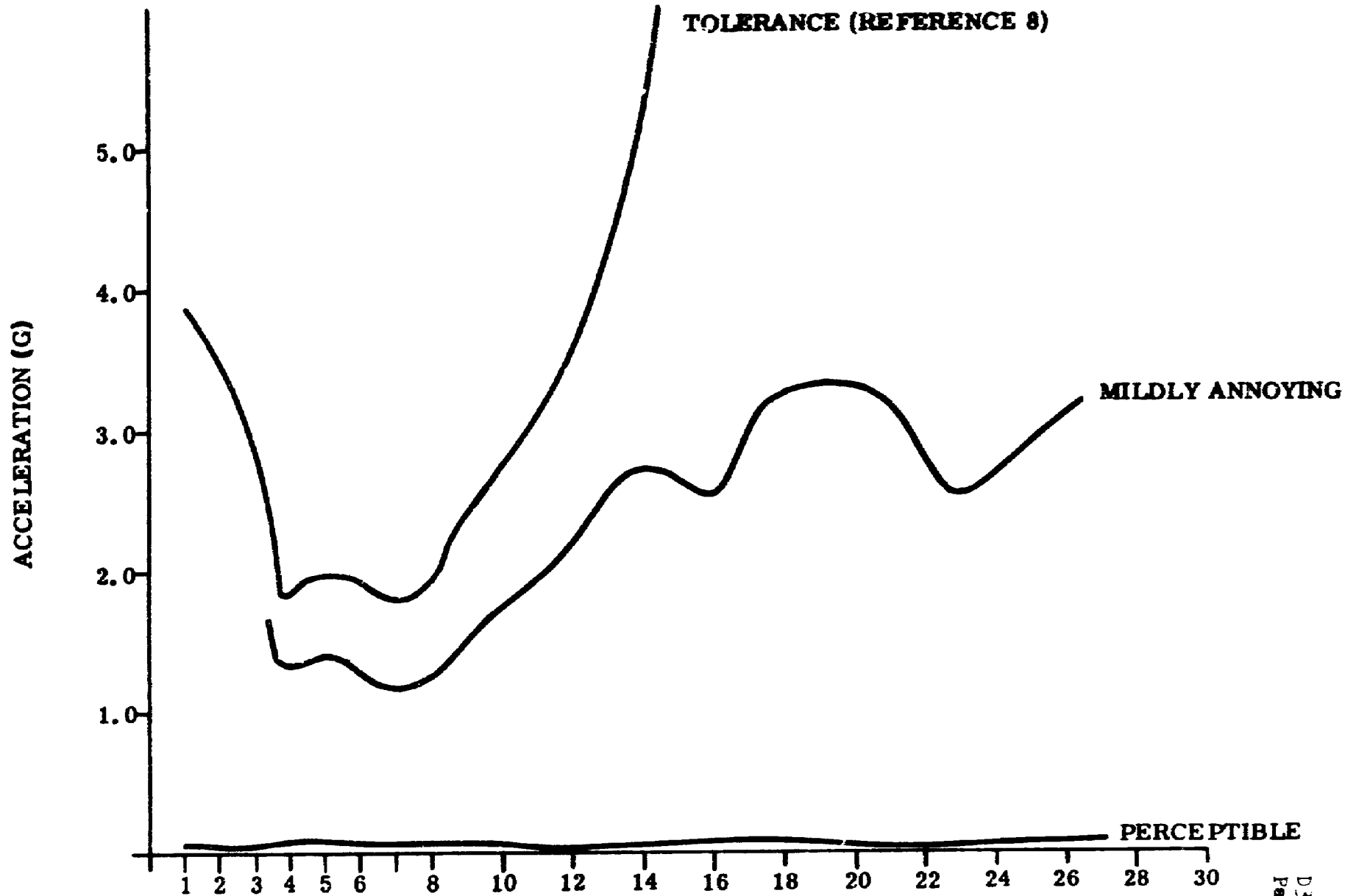

TOLERANCE (REFERENCE 8)
MILDLY ANNOYING
PERCEPTIBLE
ACCELERATION (G)
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 8 10 12 14 16 18 20 22 24 26 28 30

FIGURE 43B
SUBJECT #8 SECOND SERIES OF TESTS

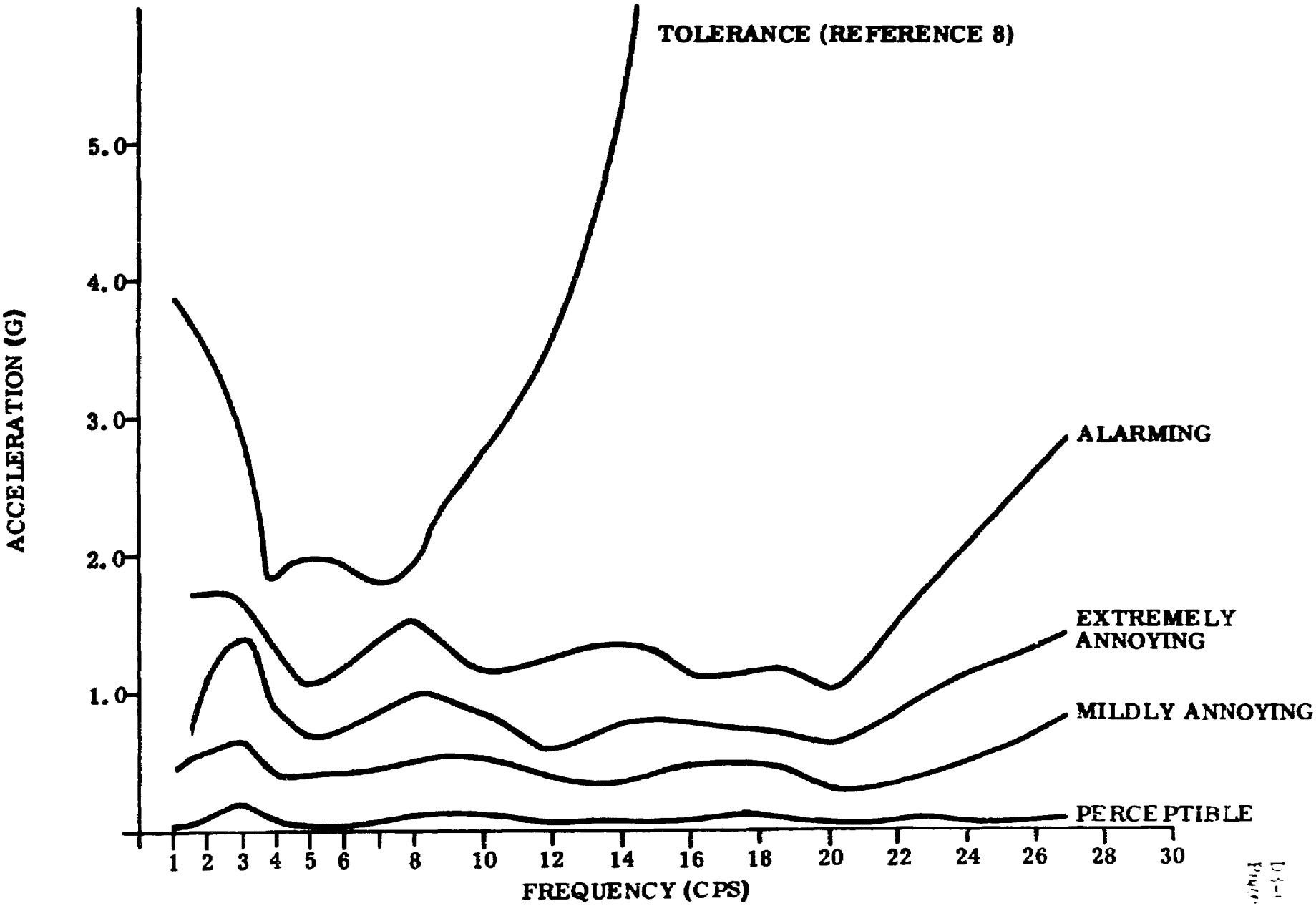


FIGURE 43A
SUBJECT #8 FIRST SERIES OF TESTS

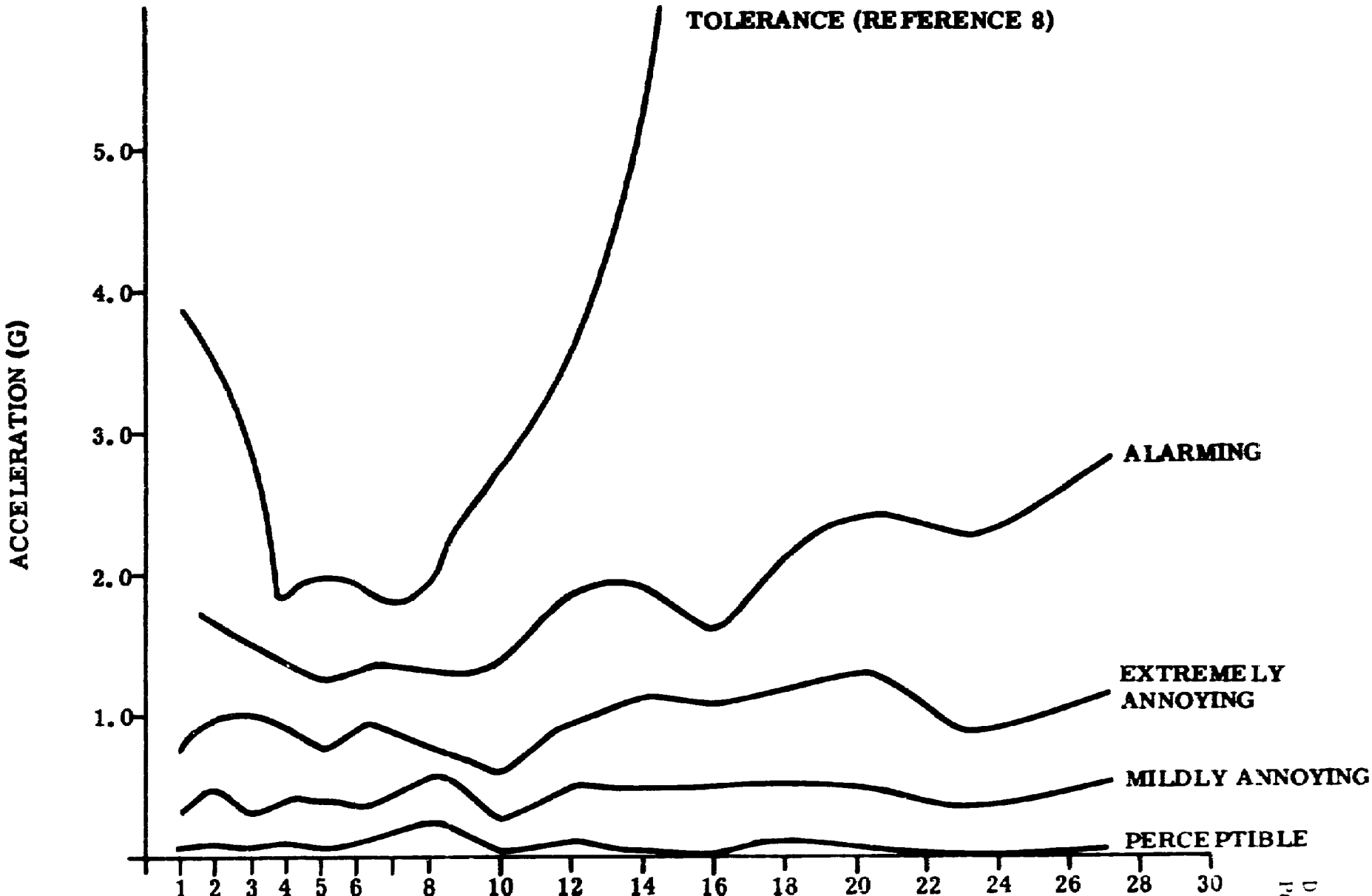

TOLERANCE (REFERENCE 8)
ALARMING
EXTREMELY ANNOYING
MILDLY ANNOYING
PERCEPTIBLE
ACCELERATION (G)
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 8 10 12 14 16 18 20 22 24 26 28 30

FIGURE 44B

SUBJECT #9 SECOND SERIES OF TESTS

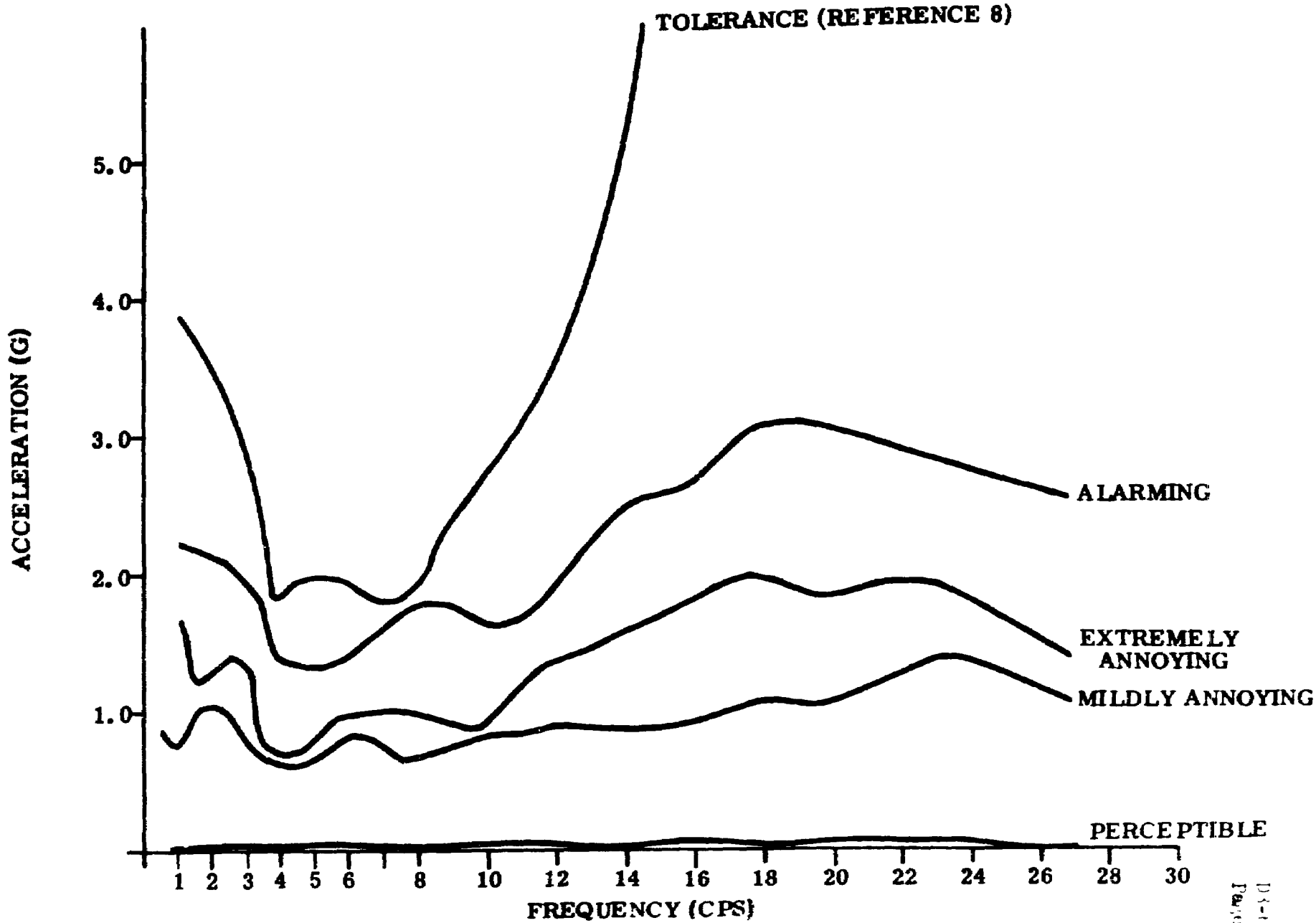
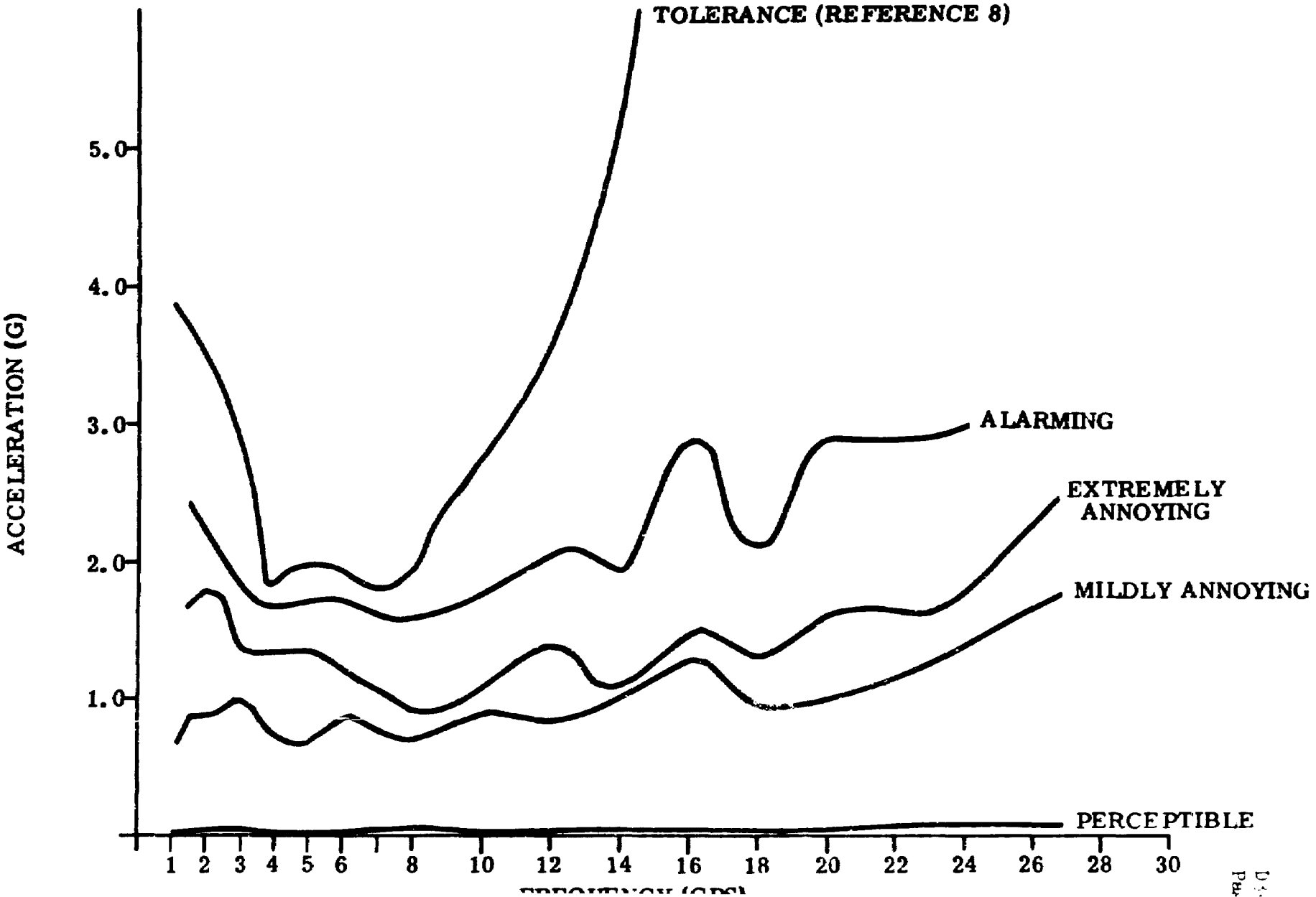


FIGURE 44A

SUBJECT #9 FIRST SERIES OF TESTS


TOLERANCE (REFERENCE 8)
ALARMING
EXTREMELY ANNOYING
MILDLY ANNOYING
PERCEPTIBLE
ACCELERATION (G)
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 8 10 12 14 16 18 20 22 24 26 28 30

SUBJECT #10 SECOND SERIES OF TESTS

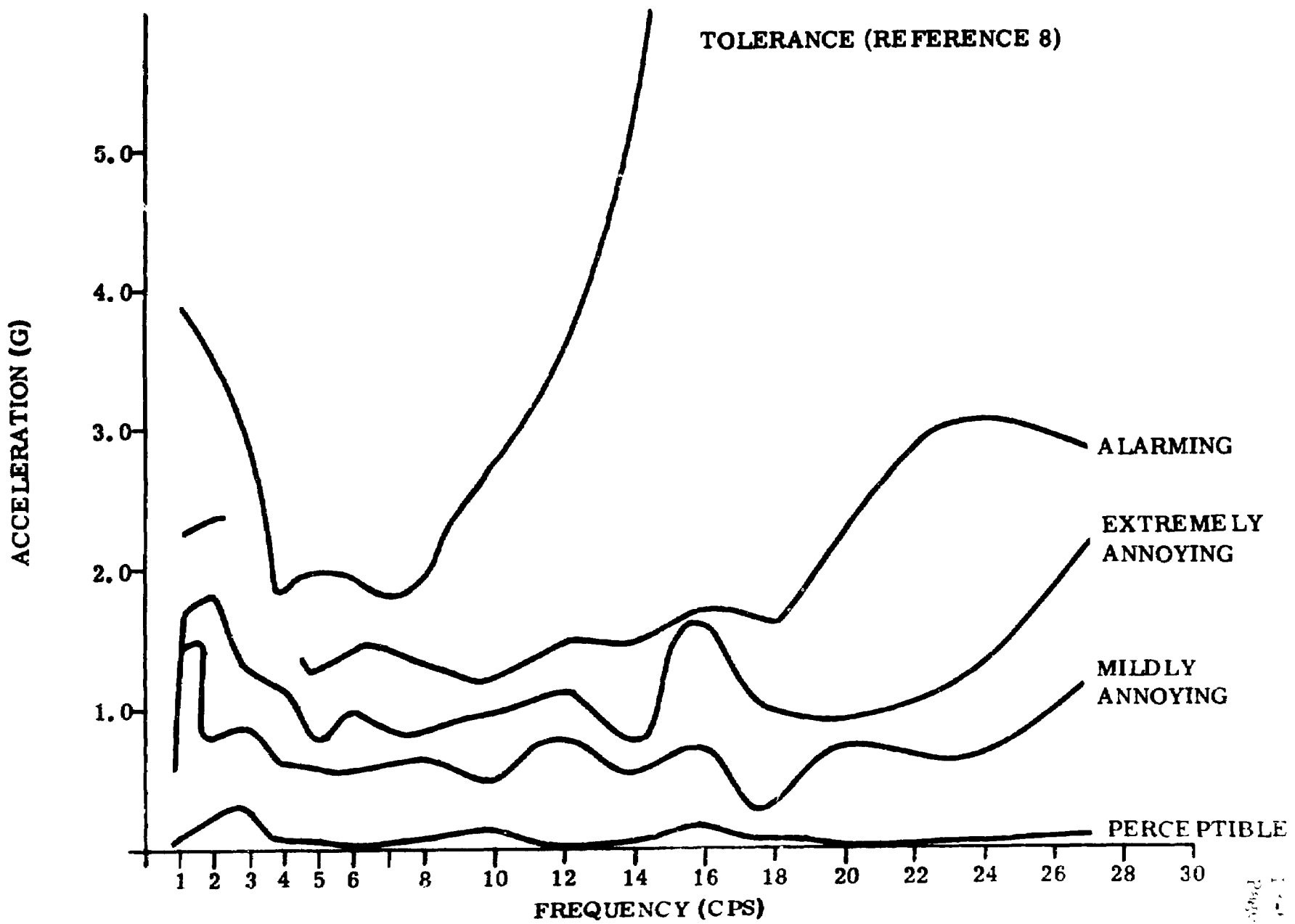
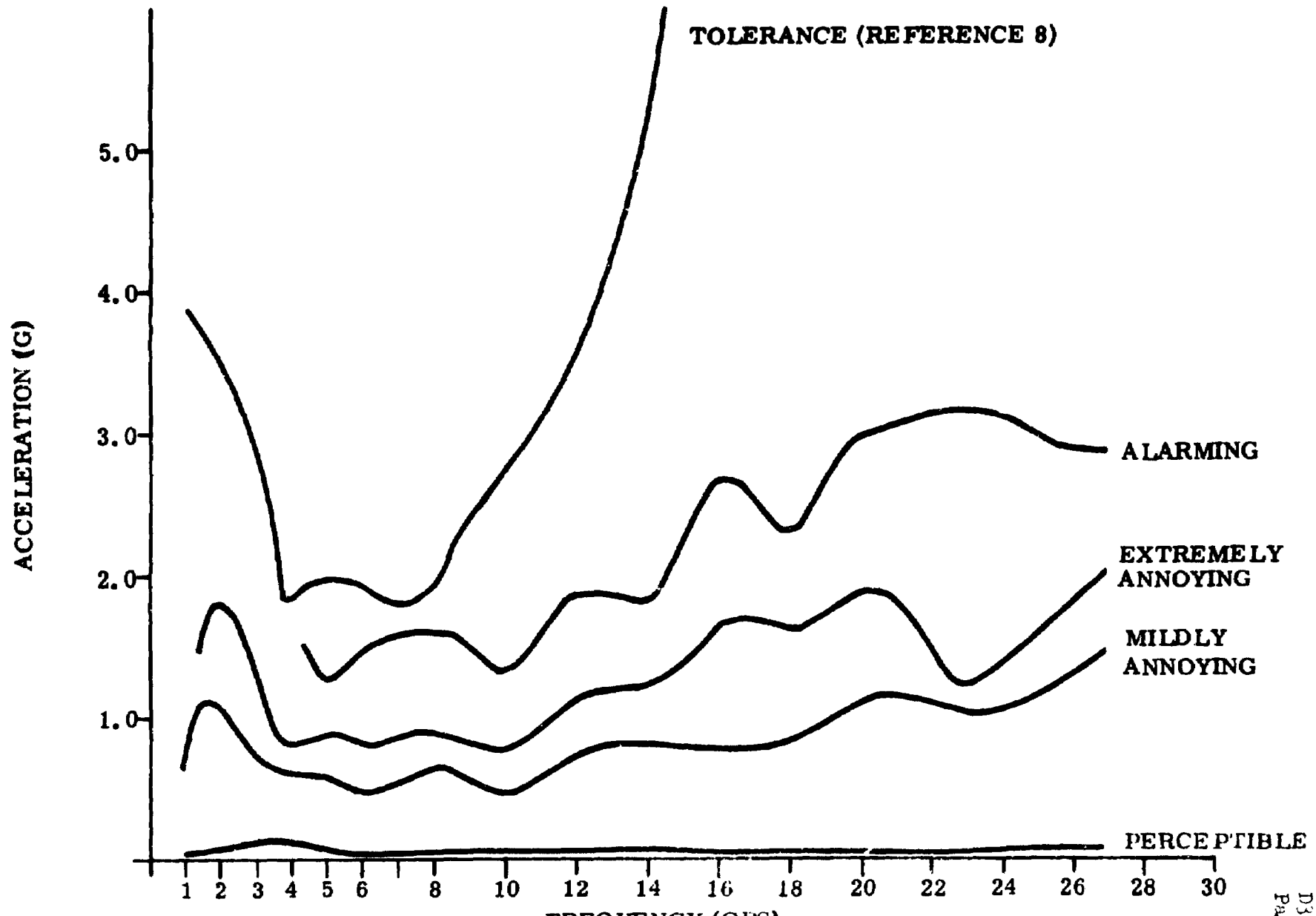


FIGURE #45A

SUBJECT #10 FIRST SERIES OF TESTS


TOLERANCE (REFERENCE 8)
ALARMING
EXTREMELY ANNOYING
MILDLY ANNOYING
PERCEPTIBLE
ACCELERATION (G)
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 8 10 12 14 16 18 20 22 24 26 28 30
FREQUENCY (CPS)

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Raymond A. Lawn, M.D. - subject medical examinations and monitoring.

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